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HERMETIC SEAL EVALUATION FOR ELECTRONIC COMPONENTS
Final Report

Prepared under Contract No. NAS 8-20109 by
J. I. Paulk, R. D. Guyton, D. T. Simpson,
M. E. Triplett, J. V. Pace, III, and J. R. Kannard

MISSISSIPPI STATE UNIVERSITY

For

NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER
Huntsville, Alabama

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Quality and Reliability Assurance Laboratory

NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER

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I. INTRODUCTION

In the past, it has been found that hermetically sealing electronic components to prevent the working parts from being exposed to environmental changes enhanced reliability and insured a longer operating life. To verify the quality of the hermetic seals, electronic components were leak tested usually by either the Radioactive Gas (RAG) Method or the Helium Mass Spectrometer process (HMS).

For some time it had been observed in hermetic seal evaluation that the RAG method often appeared to lack correlation with the more commonly used HMS method. It was plausible that a systematic difference might exist as a result of the different properties of the different gases involved in the two testing methods. The establishment of a realistic maximum acceptable leak rate limit was also of interest not only to the user but also to the vendor of electronic components. If the leak rate limit could be relaxed, the manufacturer would have fewer rejected components during the leak rate inspection;and a substantial reduction in manufacturing costs could be realized.

The leak rate limit of 10^{-8} atm. cc/sec. was apparently based upon manufacturing capabilities and not upon the quality requirements of the device or effects of contamination on quality requirements. This investigation was initiated to determine a realistic maximum acceptable leak rate limit and also a correlation, if any, between the two leak detection methods.

The first phase of this work was to establish a critical leak rate limit by choosing test components of three types: a crystal can relay, a half size

crystal can relay, and a semi conductor of case size TO-5. Figures 1, 2, and 3 illustrate the component types. The semi conductors were not to be of the planar passivated construction in order that contaminants would have maximum effect on the internal construction of the devices. All components passed screening requirements to MSFC specifications with the exception of the seal leakage requirements. These requirements were relaxed in order to get the required number of leakers.

To have sufficient numbers of components to support a statistical analysis, at least two hundred components of each type were proposed. These components were hand picked by the manufacturer using the HMS method so that a spectrum of leak rates ranging from 10^{-4} to less than 10^{-9} atm. cc/sec. were obtained. Components were placed in groups according to leak rate values and serialized to facilitate individual data records. Components were then transported to Mississippi State University at ambient temperatures in sealed containers pressurized to one absolute atmosphere with nitrogen.

Upon receipt the components were tested using the RAG Method and the leak rates again determined. At this point, the components were divided into two groups: a control group to be life tested only and a test group to be exposed to selected environmental conditions and then life tested.

The environmental exposure was intended to be as realistic as possible consistent with the practice of transporting the assembled or essentially completely assembled space vehicle to Cape Kennedy, its subsequent residence at the Cape, and later residence in a near vacuum condition.

The exposure consisted of salt fog spray and humidity concurrent with variations in temperature over the range from room ambient to 150 F. The time at each temperature was 12 hours at each level during each 24 hour period, and a total testing time of 96 hours was selected. Following the salt fog

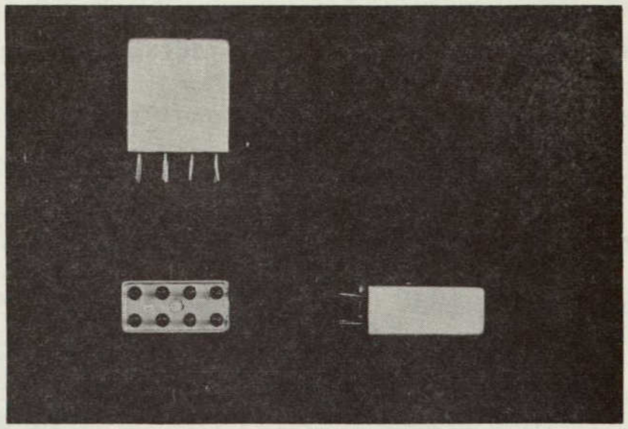

Figure 1. Full Size Relay

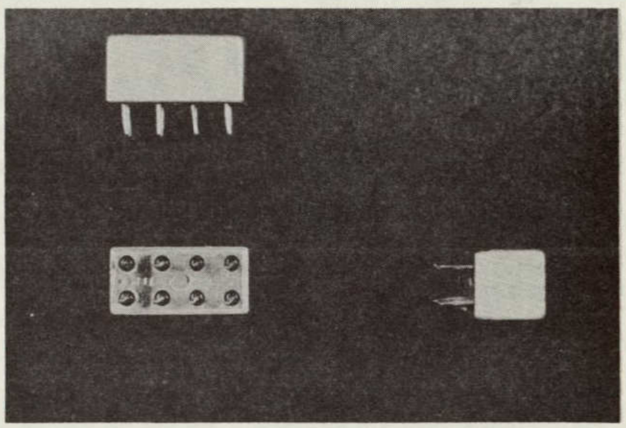

Figure 2. Half Size Relay

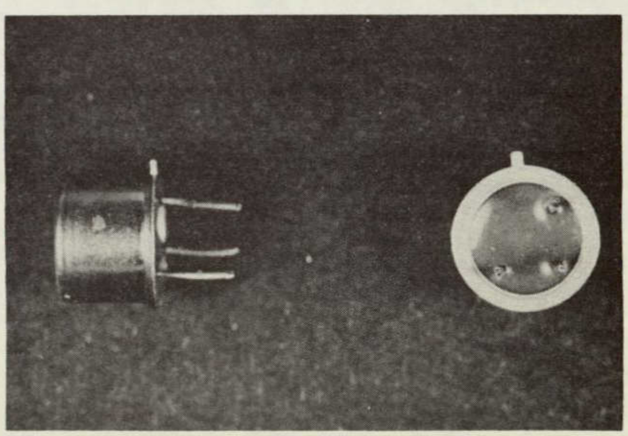

Figure 3. Transistor of 2N1613 Family

environment, the test components were placed in an altitude chamber capable of absolute pressures corresponding to an altitude of at least 150,000 feet and temperatures at least as low as -85 F. A total time of 14 days at altitude with the temperature remaining at -65 F for 12 hours and + 150 F for 12 hours of each 24 hour period were the selected environmental conditions. After the removal of the components from the altitude chamber, electrical testing was performed prior to life testing.

The authors of this report assisted by undergraduate workers designed and constructed life testers for the relays and the transistors. Life testing was initiated after electrical test had been completed.

A correlation of leak rates based upon the mass spectrometer data and the RAG data was begun, and conversion factors for converting rates determined by one testing method to leak rates by the other were determined. It should be noted that the HMS Method was used only once, and this test was performed at the vendor's plant.

II. FINDINGS AND RECOMMENDATIONS

(a) Findings:

1. Over the entire leak rate range which was considered ($2x10^{-9}$ to $2x10^{-5}$ atm cc/sec. based upon helium) neither the full size crystal can relay (S2GP-6-54) nor the half size crystal can relay (S2GP-7.25-73) exhibited any significant change in the mean time to reach the selected criteria to failure between the test groups and the control groups. This indicated that the contaminants had not materially affected the relays in the test groups. This was not to indicate, however, that prolonged exposure to near vacuum conditions might not have an effect upon relay life. It is also possible that the leaking relays may have ceased to leak during the salt fog exposure thus blocking the entry of contaminants.
2. The comparison of leak rates based upon the HMS method to those based upon the RAG Method indicated that no single correlation factor could be obtained. Instead, three separate correlation factors were determined which depended upon the flow mechanism. In no case was a one to one correspondence obtained.
3. The exposure of relays to a salt fog environment caused the build-up of a conduction path between the relay pins and the relay case causing an unacceptable low value of resistance between the pins and the case. Case to pin resistances of less than 1000 megohms were observed. The conducting material was difficult to remove; and, in some cases, the use of a small wire brush was ineffective in removing it.

4. The half size crystal can relay, S2GP-7.25-73, had a superior life time to that of the full size crystal can relay, S2GP-6-54. The mean time to failure of the half size relays was almost three times as long as the mean time to failure of the full size relays. It was evident from the tests that were conducted that the half size relay was superior to the full size relay secured from the same manufacturer. This may have been due to the challenge of producing a reliable product of smaller size.
5. Our efforts to obtain non-passivated transistors met with no success. Passivated transistors of the 2N1613 family were obtained which had failed the seal leakage test on a go-no-go basis. When leak tested with the RAG Method, the transistors either did not leak or leaked in a gross fashion. Therefore no further correlation was attempted between the two leak detection methods by using the transistors. Also, the transistor leads weakened and broke after exposure to the salt fog enivronment.
6. Two unique life testers were designed for use in life testing relays and transistors. Both testers functioned well during the life testing procedures. It should be mentioned that these testers caused the components to be subjected to more rigid conditions than are usually encountered in life testing.

(b) Recommendations:

1. The selected environmental exposure had a negligible effect on the half size and full size relays other than to produce conduction paths between the pins and the case. It is recommended that leaking relays be life tested under extended vacuum conditions to determine if such conditions cuase any significant change in useful life.

2. The correlation factor between the RAG Method and the HMS Method varied with the flow mechanism. This indicated that a single RAG test would not simultaneously reveal the absolute leak rate and the flow mechanism. If, however, the leak rate value were desired to an accuracy within one order of magnitude under usual soak pressures and soak times, then a single RAG test could be accepted. In any event, it is recommended that if only a single RAG test is to be made, then the assumption should be made that the flow is molecular. The calculated flow rate value will then be conservative.

   The direct reading HMS method developed by the General Electric Company for this project is considered to be an exact method for determining leak rates prior to final sealing. It should be recognized, however that a final leak test must be made on the sealed, completed product. It is understood, of course, that a conversion factor from helium to air must be used or leak rate limits must be specified in terms of the leakage of helium.

3. Since the buildup of conduction paths between the pins and the case were observed, it is recommended that relays in space vehicles which may be exposed to a salt fog environment have sample relays of the type which were tested be removed after exposure to such an environment and checked for case to pin resistance of less than 1000 megohms.

4. The transistor leads weakened and broke after exposure to the salt fog environment. It is recommended that a humidity test or salt fog test be included as part of the lot sampling specifications required in the qualification of transistor vendors.

III. PROCUREMENT OF COMPONENTS

(a) Procurement of Relays:

During the summer of 1965 a representative of Mississippi State University went to the General Electric Company plant at Waynesboro, Virginia to secure relays of types S2GP-6-54 and S2GP-7.25-73. Two hundred and fifty relays of each type were to be hand picked so that 50 would have leak rates in each of the following ranges:

LEAK RATE RANGE Atm. cc/sec
10^{-8} or better
10^{-8} to 10^{-7}
10^{-7} to 10^{-6}
10^{-6} to 10^{-5}
10^{-5} to 10^{-4}

The relays were to be taken from the normal production runs whenever possible using the following general procedures:

1. Assembled relay, complete except for final seal port weld, was leak tested by attaching the relay to the mass spectrometer pump by a tube from the seal port. The relay was placed in a 100% helium atmosphere, and the leak rate was measured.
2. Relays were serialized, the leak rate was recorded, and sorting into leak rate categories was accomplished.
3. Relays were filled with 100% dry nitrogen, the seal port was welded closed, and the weld was soldered over. Seal port welding was performed in a dry box containing 100% dry nitrogen.
4. Seal degradation by repeated welding stresses was performed where necessary to obtain leaking components in certain leak rate categories. This was accomplished by using the electron beam welder.

5. All relays accepted from the vendor had passed electrical and mechanical screening tests given in appropriate MSFC procurement specifications except the seal leakage requirement.

6. Relays were transported to State College, Mississippi, by automobile in seal metal containers pressurized to 1 atmosphere of dry nitrogen.

After a period of six weeks, it became apparent that an unlimited amount of time would be required to secure the exact number of relays in each leak rate category. Thus, the number of categories was reduced to 4, and the number of relays selected in each category based only upon HMS testing was as follows.

FULL SIZE CRYSTAL CAN RELAYS (S2GP-6-54)

Leak Rate Range atm cc/sec	Number of Relays in Group
2×10^{-9} to 2×10^{-8}	36
2×10^{-8} to 2×10^{-7}	61
2×10^{-7} to 2×10^{-6}	76
2×10^{-6} to 2×10^{-5}	65

HALF SIZE CRYSTAL CAN RELAYS (S2GP-7.25-73)

Leak Rate Range atm cc/sec	Number of Relays in Group
2×10^{-9} to 2×10^{-8}	61
2×10^{-8} to 2×10^{-7}	69
2×10^{-7} to 2×10^{-6}	64
2×10^{-6} to 2×10^{-5}	44

All other relay selection procedures outlined in our test program submitted to MSFC were followed as proposed.

It should be mentioned that the General Electric Company representatives were exceptionally cooperative in the endeavor and made every effort to supply us with relays in accordance with our needs.

The General Electric Company also devised a new technique for HMS

testing. This was concerned with the method used to provide a helium atmosphere for the relays. Figure 4 illustrates how a rubber finger cover was attached to the base of the relay. A hole was cut in the normally closed end of the finger cover, and a line from the helium supply was inserted into the hole. Figure 5 shows how this was accomplished.

(b) Procurement of Transistors:

The contract specified that 200 transistors of a special type of 2N1613 be procured for this project. An average of 40 transistors were to be obtained in each of five leak rate categories. In addition, the contract required: "These semiconductors must not be of a planar passivated construction in order that contaminants will have maximum effect on the internal construction of the device."

Several of the major semiconductor manufacturers were contacted in an attempt to buy these special transistors. The information obtained from these attempts led to the conclusion that no one in semiconductor technology made the 2N1613 except those of a planar passivated type of construction. Finally, the Texas Instrument Company agreed to furnish at no charge transistors of the 2N1613 family which had failed the leak rate test on a go-no-go basis. These were rejected transistors that had not been checked for compliance with other specifications normally required for the 2N1613. This contractor agreed to accept the transistors for possible further use in the proposed life testing program. If possible, the transistors would be categorized according to leak rate after receipt from the Texas Instrument Company.

After the transistors were received, they were checked by the contractor in a circuit similar to the one in the transistor life tester. Those which passed the tests in the three regions of active, cutoff, and saturation

were accepted. About 25% of those received failed this test. The majority of these failures were attributed to variations among transistors of the 2N1613 family and were not, in most cases, due to an inferior product.

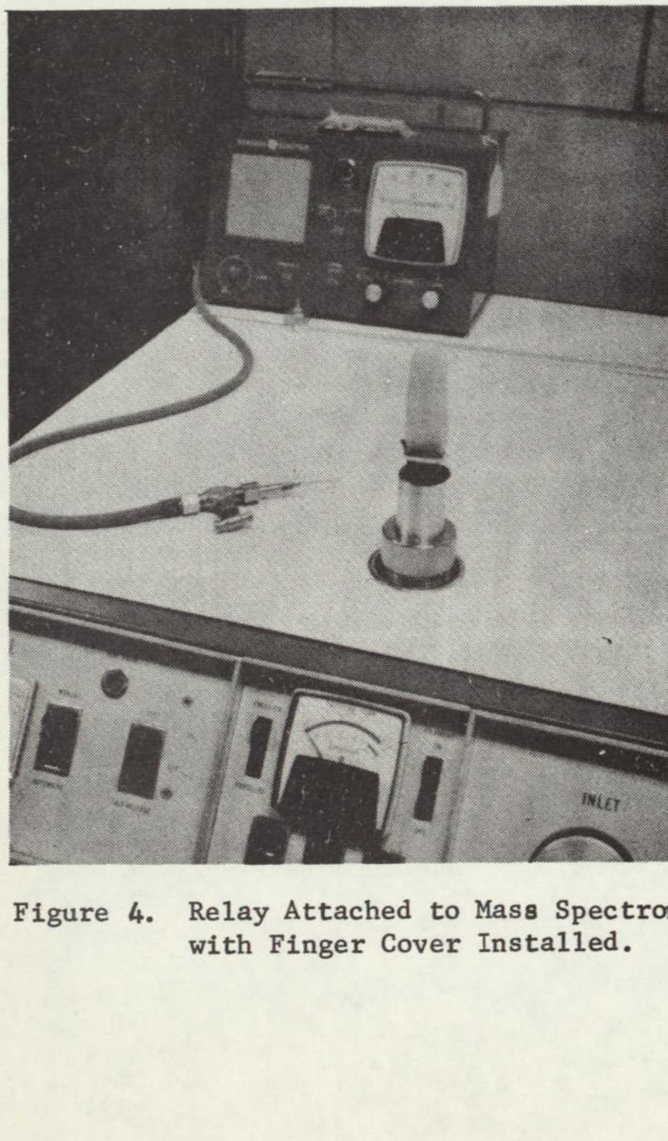

Figure 4. Relay Attached to Mass Spectrometer with Finger Cover Installed.

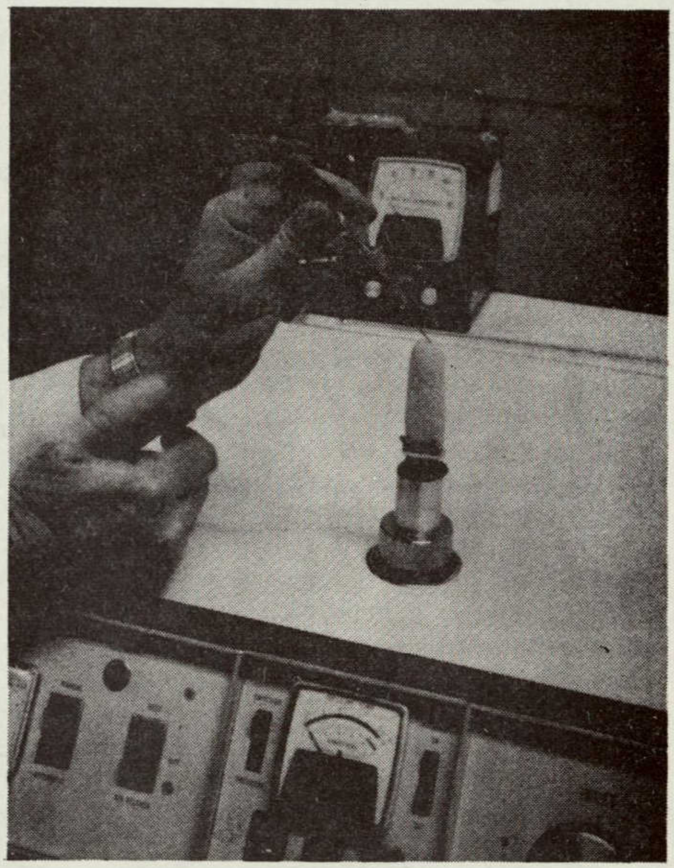

Figure 5. Helium Line Providing Helium Atmosphere For Leak Rate Determination.

IV. DESIGN AND CONSTRUCTION OF THE LIFE TESTERS

(a) Relay Tester:

The design of the relay tester was based upon a compromise between manual and automatic operation in order that construction could be accomplished at a minimum cost to the Government consistent with the time limitations for testing required by the contract. The testing specifications were intended to simulate operational conditions and to determine the expected life of a relay while providing means for detecting and isolating the causes of failure. A failure was defined as any significant change of electrical characteristics which were monitored during the proposed tests.

The electrical characteristics to be monitored during operational cycling of the relays at 20 cycles per minutes were:

1. Miss
2. Weld
3. Bridge
4. Contact Resistance
5. Insulation Resistance

In addition, prior to operational cycling and after the environmental exposure, the following tests would be performed:

1. Insulation resistance check
2. Electrical checks:
    a. Operational and release voltages
    b. Contact resistance
    c. Direct current coil resistance or current at 28 volts DC

These tests were also perfomed after 10,000, 110,000 210,000 and 310,000 operating cycles.

A complete description of the relay tester construction and operation is given in M. E. Triplett's, "Design, Construction, and Testing of a Life Tester for Hermetically Sealed Electronic Crystal-Can Relays." (1)

(b) Transistor Tester:

Since there was no defined method of life testing for a transistor, a method was chosen with the objective of accelerating the life test to reduce the testing time. The tester was designed to operate each transistor through a repeated three part cycle of approximately four minutes duration per part. The transistors were to be operated in the active region at rated dissipation, in the saturation region, and in the cutoff region. At no time were any of the ratings of the transistor to be exceeded, and this particular sequence of life testing would cycle the junction temperature between the approximate limits of room ambient and 200 C. This temperature cycling should accelerate the life testing.

Failure of a transistor during each phase was defined as follows:

1. Failure in the active region was defined as a $\pm$ 10% change in the DC current gain or, equivalently, a $\pm$ 2 volt change in V_{ce}.

2. Failure in the saturation region was defined as V_{ce} (Sat) $\geq$ 1.0 VDC.

3. Failure in the cutoff region was defined as $I_{cbo} \geq 10$ na.

The life tester was designed to run continuously with tests for failure to be performed periodically. Tests for failures could be performed as frequently as desired although it was considered desirable to perform the test in each of the three regions at least once a week. For a complete description of the transistor life tester see R. D. Guyton's "Operating Manual for the Transistor Life Tester." (2)

V. RAG TESTING OF COMPONENTS

The RAG method has been used extensively to determine the leak rates of hermetically sealed components for space applications. Under a previous contract with the National Aeronautics and Space Administration a RAG system was constructed at Mississippi State University. The only major difference between the MSU unit and the commercially available unit was a lack of automation. Each test conducted using the MSU unit was performed manually instead of automatically. Figure 6 is a block diagram of the MSU unit which functioned in the manner described below.

Components to be tested were placed in the activation tank which was then evacuated by the vacuum pumps. Valves were adjusted, and the radioactive gas, Kr-85 and dry nitrogen from the storage tank, was transferred through the compressor to the activation tank. The gas remained in the activation tank for a preset soak time at a predetermined pressure and was then returned to the storage tank. The activation tank was evacuated and flushed with air several times. Components were removed from the activation tank and placed on a 1" x 1" NaI scintillation crystal. A determination of the contained activity was accomplished by using a Nuclear Chicago Model 1620CS Count Rate Meter. The count rate obtained in that fashion was proportional to the activity of the residual radioactive gas remaining in the component. Reference sources were prepared by pipetting a known amount of radioactive gas into a component of the same type as those under test for leak rate determination.

(a) RAG Testing of Relays

After receipt of the relays from the General Electric Company RAG testing of the relays was initiated. In an early phase of the testing, it was observed that several of the relays in each leak rate range had ceased to leak.

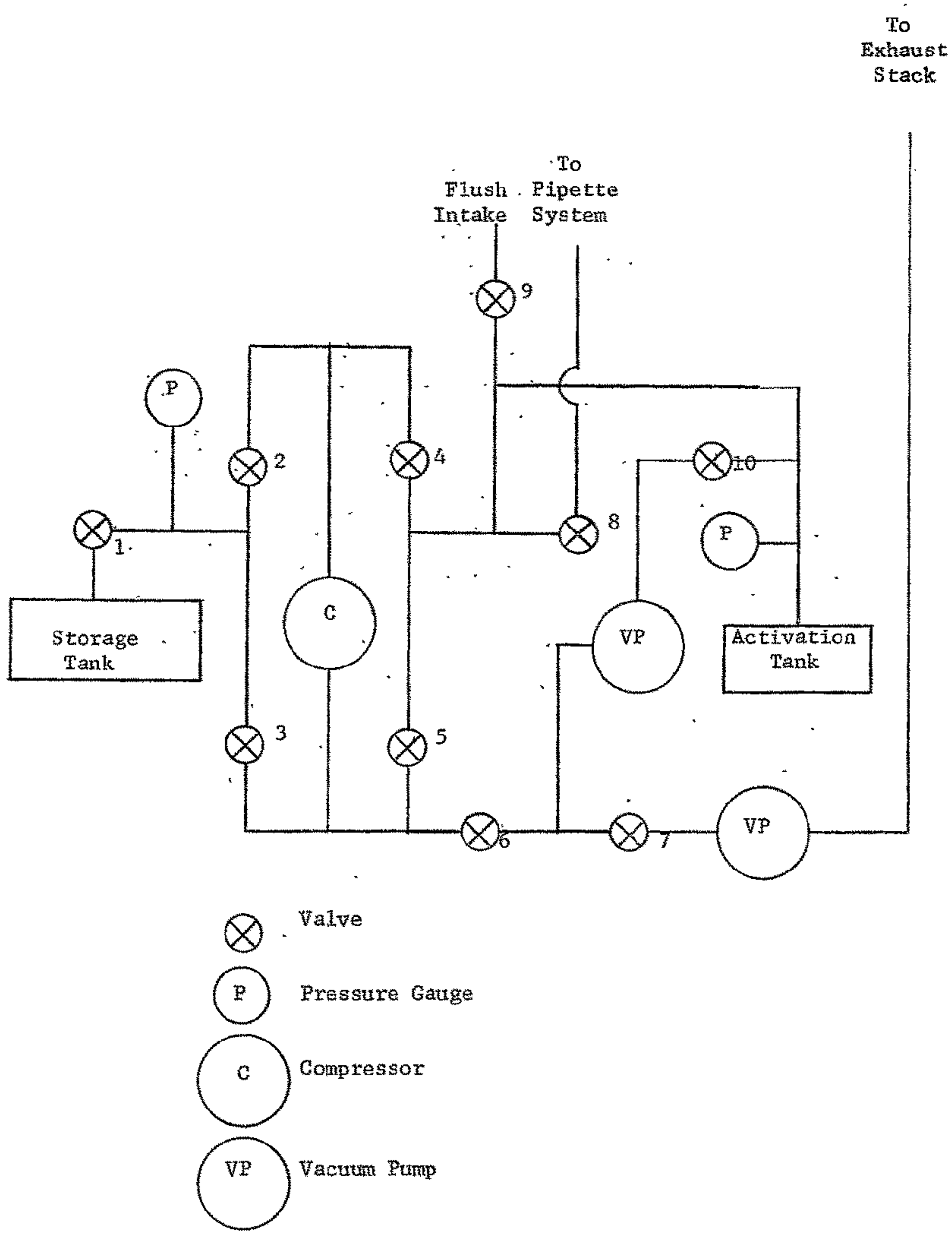

Fig. 6: MSU RAG System

This occurred although the relays were transported to State College, Mississippi in an atmosphere of dry nitrogen and stored in desiccator jars when not being soaked in the RAG system or being counted with the scintillation counter. It was apparent that these relays could not be used for a correlation of leak rates between the two testing methods since a comparison of a reading of zero or no reading with a finite value yields no correlation at all. Other relays with very low leak rates on the mass spectrometer would have required up to 100 hour soak periods for a detectable amount of RAG gas to be forced into the case at reasonable pressures. This was apparent even though a special shield was constructed around the detector which reduced the background level to about 100 cpm. Therefore, only about forty-one percent of the relays could be tested which yielded meaningful results. Appendix Tables B1 and B2 tabulate the leak rates from the RAG test along with the corresponding leak rates from the HMS tests.

Each relay was soaked six times, twice at each of three soak pressures. The data was analyzed by the method of least squares as indicated in section VIII of this report. Each value of leak rate was considered to be a mean value of the six determinations, and the standard deviation for the mean value was determined. The ratio of the leak rate by the RAG method to that by the HMS method

$$R = Q_s^R / Q_s^{MS} ,$$

was then determined and the standard deviation was calculated. This was also considered to be a mean value. The grand mean of the means for each leak rate regime was then calculated along with its standard deviation. A very good correlation between the theoretical ratio for the molecular regime and the experimental ratio was obtained.

(b) RAG testing of Transistor:

Since only one company agreed to furnish transistors of the 2N1613 family and these were to be those which had failed the leak test on a go-no-go basis, we planned to categorize the transistors using the RAG system. Upon receipt, however, it was determined that the transistors either leaked in a gross fashion or not at all. Thus, no useful data could be obtained from RAG testing the transistors.

(c) Radiation Safety Considerations:

Throughout the entire RAG testing of components none of the operators of the RAG system received greater than a small fraction of the radiation dose allowed for radiation workers during any one week period.

VI. SELECTED ENVIRONMENTAL EXPOSURE

All components in the test groups were subjected to the same environmental exposure with the exception of the altitude exposure of transistors. Generally this consisted of two phases. The first of these was exposure to salt fog environment with variations in temperature.

The components were placed on test tube racks and positioned in the Industrial Filter and Pump Company, Type 411-2ACO, salt fog chamber so that the spray from the nozzle did not impinge directly onto the test specimens. The 20% salt solution was made using technical grade sodium chloride and tap water which contained less than 200 ppm of dissolved solids. Salt fog spray was continuous, and the temperature inside the cabinet was varied from room ambient to 150F. The time at each temperature was 12 hours during each 24 hour period. Components were inspected once daily to determine that corrosion of any component was not excessive. The total testing time was 96 hours, after which the test specimens were removed from the cabinet.

After removal of the specimens, each was washed with warm water and air dried. At this stage it was observed that the transistor leads were very weak and some broke off where the lead enters the transistor header. This had not been observed during any of the daily inspections. It was apparent that the salt had chemically reacted with the lead materials. Since one or more leads on most of the transistors was affected in this fashion, it was not possible to initiate their life testing. Qualitative analysis of the lead materials were made by the Mississippi State Chemical Laboratory. The results of the analyses are given in Appendix C. The relays were affected by the spray in quite a different fashion.

The use of warm water and air drying to remove residual salt from the

relays was not effective. Bench tests of the electrical characteristics later revealed that all test relays failed due to low pins to case resistance. This was not discovered, however, until the specimens were removed from the altitude chamber.

Following the salt fog environment, the relays were placed in an altitude chamber and this phase of exposure began. The chamber was maintained at an absolute pressure corresponding to 150,000 feet and a temperature of 150F for 12 hours and an absolute pressure corresponding to 90,000 feet and a temperature of -65F for 12 hours of each 24 hour period. Relays remained in the chamber for 14 days. They were then removed, bench tested electrically, cleaned with

VII. LIFE TESTING OF COMPONENTS

(a) Life testing of Full Size Relays:

Two hundred and forty-five S2GP-6-54 full size crystal can relays were electrically checked upon removal of the test group from the altitude chamber. All relays in the test group failed these tests due to low pin to case resistance. A close observation of the relays revealed a gray deposit between the pins and the case which apparently provided a conduction path. Although the relays had been cleaned with warm water and dried with air before the test, it was apparent that more rigorous cleaning procedures would be required. A small wire brush was then used to remove the deposit. Even then, some of the relays failed this part of the test. It was decided, however, that as many relays as possible would be used in the determination of the mean time to failure by operationally cycling the relays in the tester.

After the initial electrical checks were completed, two hundred and forty relays were used in the tester for the start of operational testing. An initial goal of 20% failures was set, at which time, the testing would be terminated. It was later decided, however, since sufficient half size relays were not ready for life testing when 20% of the full size relays had failed, that testing would be continued until 50% of the relays had failed. Bench tests of electrical characteristics were repeated at 10,000 operating cycles and each 100,000 operating cycles thereafter. Appendix Table A1 is a compilation of the bench test data for full size relays. It should be noted that there were two and one-half times as many bench test failures in the test group as in the control group due to low resistance between the pins and the case. This may have been brought about by the residual deposit remaining after the salt fog test. Other failures occurred during operational cycling.

Appendix Tables A3 through A6 and Figures A1 through A4 illustrate the failures which were detected during operation of the tester. The figures represent a Weibull analysis (4) to determine the mean time to failure for relays in two large leak rate ranges. Leak rates were based upon the HMS test only.

It is apparent from these data that over the leak rate ranges considered there were no significant differences in the mean times to failure for relays of one groups as compared to the other or between a test group and the corresponding control group. This is further emphasized by Appendix Tables A1 through A18 and Figures A9 through A16 where the total leak rate range has been further subdivided. Table A19 lists the causes of failure during operational cycling and indicates that the predominant cause of failure was an unacceptable high value of contact resistance.

(b) Life Testing of Half-Size Relays:

Two hundred and forty-two S2GP-7.25-73 half size crystal can relays were electrically checked upon removal of the test group from the altitude chamber. Again all relays were brushed to remove residual contamination from the salt fog exposure. Initial and subsequent bench test results have been tabulated in Appendix Table A-2 where again it was evident that failures at these stages predominated in the test group. Life testing was initiated.

Appendix Tables A3 through A6 tabulate the cycles to failure of relays in the test and control groups over two broad leak rate ranges. Figures A5 through A8 illustrate the Weibull analysis of the mean times to failures for the half size relays. Again no significant variations between the mean times to failure for relays in each group were observed. No further break down into a greater number of groups was attempted since only 20% of the relays had failed after a considerable testing time. Appendix Table A20 lists the causes

of operational failures and clearly confirm the predominant cause as an increase in contact resistance beyond acceptable limits.

(a) Life Testing of Transistors:

One half of the transistors of the 2N1613 family were exposed to selected environmental conditions prior to life testing. During their residence in the salt fog chamber they were examined daily to determine if excessive corrosion was occurring. Only at the end of the 96 hour exposure period was the discovery made that one or more leads had corroded to the extent that they broke off at the point of entry into the header. It appeared that the salt had chemically reacted with the leads at the point and caused them to weaken or break. Since most of the test group had one or more leads so affected, it was decided not to run the life test part of the project as originally contemplated as there were not enough transistors which had survived the environmental test.

One hundred and six transistors were available from the control group, and these were placed in the life tester to complete the checkout of its operating characteristics. Roughly one-third of these were placed in each of the three groups of the life tester so that the power supply would have the same load at all times during the life test.

The bias potentiometers were adjusted to set V_{ce} to approximately 20 volts for each transistor operating in the active region. The life tester was operated continuously for 1000 hours. Each transistor was checked three times per week during this period to determine if it had failed in either the active, saturated, or cutoff regions. Four transistors apparently failed during this 1000 hour test.

After 127 hours one transistor failed in the cutoff region as I_{cbo} greatly exceeded 10 na. It did not fail in the active or saturation regions

for the remainder of the 1000 hour test. The second failure occurred after 248 hours and was the same type of failure during cutoff. This transistor also did not fail in the other two regions for the duration of the test. The third apparent failure after 248 hours was in the active region, but an investigation showed that the transistor was not properly inserted into its socket. Thr fourth apparent failure occurred after 1000 hours with a change of V_{ce} of greater than two volts while in the active region. When this transistor was pushed flush with its socket, the change in V_{ce} was less than 2 volts indicating that it had not failed.

In summary, two failures occurred during the 1000 hour life test; and both were increases in I_{cbo} to values greater than 10 na. This 1000 hour test simply proved the capabilities of the transistor life tester and illustrated its unique features.

The typical life tester approach is to operate each transistor at rated values in the active region. Such a tester would not have detected either of the failures detected by our transistor tester. This accentuates the advantage of testing each transistor in each of the three operating ranges.

VIII. RAG-HMS TEST CORRELATION

Standard leak rate is defined as that quantity of air measure in cm^3 per sec at STP which will flow through an opening, one side of which is at an absolute pressure of one atmosphere and the other side is at an absolute pressure of zero. The leak rate equations, assuming molecular, slip, and Poiseuille flows respectively, are then:

$$Q = Q_S^M (P_2 - P_1) \quad (1a)$$

$$Q = Q_S^M (P_2 - P_1) + Q_S^P (P_2^2 - P_1^2), \text{ or} \quad (1b)$$

$$Q = Q_S^P (P_2^2 - P_1^2). \quad (1c)$$

The volume which flows through a leak during a time "t", if the pressures on the two sides remain constant, is then:

$$V = Q_S^M t (P_2 - P_1), \quad (2a)$$

$$V = Q_S^M t (P_2 - P_1) + Q_S^P t (P_2^2 - P_1^2), \text{ or} \quad (2b)$$

$$V = Q_S^P t (P_2^2 - P_1^2), \quad (2c)$$

depending upon the leak regime which occurs.

By taking a single measurement with the RAG, one is unable to determine the flow regime or the leak rate. Repeated measurements at different pressures will, however, yield some insight as to the proper flow mechanism and will also permit a determination of the leak rate. The same problem also exists while using the HMS test on a sealed component. This was recognized before the RAG testing began; and, as a compromise between statistical accuracy and the time available to perform RAG testing, it was decided to soak the relays twice at each of three different pressures. Once these data were obtained, a least squares analysis was performed to fit each of equations (2) to the data. The normal equations for the least squares analysis were:

$$Q_S^M = \left(\sum_i V_i P_i - \sum_i V_i\right) / \, t \sum_i (P_i - 1)^2 \quad (3a)$$

$$\sum_i P_iV_i - \sum_i V_i - Q_S^M t \sum_i (P_i-1)^2 - Q_S^P t \sum_i (P_i^2-1)(P_i-1)=0 \quad (3b)$$

$$\sum_i P_i^2V_i - \sum_i V_i - Q_S^M t \sum_i (P_i-1)(P_i^2-1) - Q_S^P t \sum_i (P_i^2-1)^2=0 \quad (3b)$$

$$Q_S^P = (\sum_i V_i P_i^2 - \sum_i V_i) / t \sum_i (P_i^2 - 1)^2. \quad (3c)$$

Equations 3 were used to determine the leak rate and the flow mechanism. Appendix Figures B1, B2, and B3 are examples of the least squares analysis for one relay in each flow region. A computer program performed the least squares analysis and calculated the standard deviation for each leak rate determination. Appendix Tables B1 and B2 list the leak rates determined from RAG testing and by using the HMS Method.

The leak rates listed in Appendix Tables B1 and B2 for the HMS determinations were based upon the leakage of helium, not air. This was done since helium was used as the gas being transported through the relay cases. The indicated leak rates were read directly from the mass spectrometer and were comparisons of the flow for the unknown leak rate to that flow observed for a calibrated helium leak. The calibrated reference was claimed to be accurate to $\pm$ 10%. For that reason, the mass spectrometer determination were assumed to have a fractional standard deviation of $\pm$ 10%. Once the leak rates were determined by both methods, a correlation was made.

To perform the correlation, relays were divided into the following three categories:

(1) those exhibiting molecular flow,

(2) those exhibiting slip flow, and

(3) those exhibiting Poiseuille flow.

The ratios of the leak rates by the two method were calculated so that the ratio, R, where

$$R = Q_S^R / Q_S^{MS}$$

was determined for each tested relay. Each value of R was considered to be a mean value since several determinations were required to obtain its value. A grand mean of R was then calculated for relays exhibiting each type of flow. The results of these calculations are tabulated below:

Table VIII-1. Ratio for Each Flow Regime

Flow	Ratio: Full Size Relays	Ratio: Half Size Relays
Poiseuille	0.080 ± 0.008	0.070 ± 0.011
Slip	0.234 ± 0.033	0.466 ± 0.180
Molecular	0.313 ± 0.025	0.328 ± 0.035

The listed standard deviations are the standard deviations in the grand mean obtained by using the usual expression,

$$\sigma^2 = \sum_i (\bar{R} - R_i)^2 \,/\, n(n - 1).$$

$\bar{R}$ = Grand mean

R_i = Individual determination of the mean

n = Number of data points in each calculation of the grand manner.

From theoretical considerations, the value of the ratio, R, assuming molecular flow, is given by the square root of the ratio of the molecular masses of the gases. For Helium and air this ratio is 0.37, in fairly good agreement with the values above which were determined experimentally.

If both the full size and half size relays are considered together in the determination of the grand meanof the ratios, they are as given below in Table VIII-2.

Table VIII-2 Ratios for Each Flow Regime, All Relays Considered Together.

Flow	Ratios (R)
Poiseuille	0.075 ± .007
Slip	0.357 ± .097
Molecular	0.319 ± .021

IX. ANALYSIS OF THE LIFE TEST DATA

If a failure rate curve is constructed which represents the rate of failure as a function of testing time for components undergoing life test, it is found that the total curve may be divided into three general parts. The first of these parts may be called an early failure curve and represents the period during which poorly manufactured items are weeded out. The second part, which may or may not be characterized by a constant failure rate, may be considered as the period of useful life. A third part represents wearout failures. The second part of the curve is of primary interest in failure analysis for in that area the early failures have been eliminated and wearout has not occurred.[4]

If the failure rate during the second part is not a constant, the exponential failure model cannot be used; and a more general model must be applied One of these models and the one selected for the failure analysis of the report is the Weibull Model in life testing. This model adequately describes the failure rate if the failure rate varies with time.[4]

The instantaneous failure rate may be expressed as

$$f(t) = ABt^{B-1}e^{-At^{B}} \text{ for } t > 0,\ A > 0,\ B > 0$$

The reliability function is then

$$R(t) = e^{-At^{B}};$$

and the failure rate is

$$Z(t) = ABt^{B-1}$$

The mean time to failure may be determined by evaluating the parameters A and B through a solution of

$$\mu = \int_{0}^{\infty} tABt^{B-1}e^{-At^{B}}dt$$

which yields

$$\mu = A^{-1/B} \; \Gamma\left(1 + \frac{1}{B}\right).$$

The variance is given by

$$\sigma^2 = A^{-2/B} \left\{ \Gamma\left(1 + \frac{2}{B}\right) - \left[\Gamma\left(1 + \frac{1}{B}\right)\right]^2 \right\}.$$

An estimate of A and B may be obtained by taking the logarithm twice of the reliability function, R (t), which gives

$$\ln \; \ln \frac{1}{R\,(t)} = \ln A + B \ln t$$

The right hand side is linear in ln t; and, if we let

$$\ln t = x$$

and we estimate $F(t_i) = 1 - R(t_i)$ by letting

$$F(t_i) = (i-\tfrac{1}{2})/n$$

and thus

$$\ln \; \ln \frac{1}{R(t)} = \ln \; \ln \frac{1}{1-F(t_i)} = y,$$

the equation becomes

$$y = \ln A + Bx.$$

A least squares analysis of the data using this equation then yields A and B. It is apparent that ln A is the intercept of the curve and B is the slope. The mean time to failure may then be calculated by using the expression for μ previously shown.

The Weibull method was used in these analyses by first applying the method to the data given in Appendix Tables A3 through A6 and A7 through A10. It was evident at that point that early failures must be recognized and discarded from the analysis. Appendix Figures A1 through A8 illustrate the final Weibull Analysis for two broad leak rate ranges for each relay type. Appendix Tables A11 through A18 further subdivide the full size relay failures into

four leak rate ranges, and Appendix Figures A9 through A16 represent the Weibull analysis for these same leak rate ranges.

It was evident upon completion of the Weibull analysis that the exposure of the relays to the salt fog and altitude environments did not change the mean time to failure significantly. From these data it appeared that over the leak rate ranges under consideration the selected environmental exposure had a negligible effect.

X. RESULTS

Two types of relays were life tested with the objective of determining a critical leak rate limit. Difficulties in securing relays in sufficient quantities to span the desired leak rate range of 10^{-9} to 10^{-4} atm cc/sec. caused the range to be slightly changed from the desired span to one encompassing 2×10^{-9} to 2×10^{-5} atm. cc/sec. These ranges were based only upon the flow of helium using the HMS method. Life testing revealed the following:

1. Over the entire leak rate range under consideration the full size crystal can relays of type S2GP-6-54 and the half size crystal can relays of type S2GP-7.25-73 exhibited no significant change in their mean times to failure regardless of our selected environmental exposure. This would tend to indicate that the present leak rate limit may be too restrictive. On the other hand, life testing was not carried out in a near vacuum condition as could be experienced by a component during a long space flight. The results of these life tests then indicated that no significant contamination entered the relays which were tested; and, thus, the exposure of the relays to contamination had a negligible effect on relay life.

2. The two types of relays had significantly different mean times to failure. Table X-1 is a tabulation of the mean times to failure of each type of relay with the leak rate range divided into two broad categories.

TABLE X-1 Mean Times of Failure

Relay Types Full Size (S2GP-6-54)	Group	Leak Rate Range (atm cc/sec.)	Mean Time (cycles) to Failure
	Test	$2x10^{-7}$ to $2x10^{-5}$	162,085 ± 13,488
	Control	$2x10^{-7}$ to $2x10^{-5}$	155,712 ± 11,476
	Test	$2x10^{-7}$	157,461 ± 11,703
	Control	$2x10^{-7}$	165,110 ± 16,575
Half Size(S2GP-7.25-73)	Test	$2x10^{-8}$ to $2x10^{-5}$	434,116 ± 97,200
	Control	$2x10^{-8}$ to $2x10^{-5}$	392,063 ± 25,131
	Test	$2x10^{-8}$	373,208 ± 62,461
	Control	$2x10^{-8}$	557,239 ±178,064

From these data, the mean time to failure of the half size relays is significantly greater than for the full size relays, thus leading to the conclusion that the half size relay is superior in reliability to the full size relay.

3. The predominant cause of failure of relays was high contact resistance.

4. A salt fog environment may cause failure of a relay because of a build up of conduction paths between the pins and the case. The conduction paths are difficult to remove and reduce the case to pins resistance to lower than acceptable limits.

Leak testing by the two methods gave correlation factors which relate leak rates determined by the HMS method to leak rates determined by the RAG method. These are shown below for the various flow regimes.

TABLE X-2. Ratio of Leak Rates ($R = Q_s^R/Q_s^{MS}$)

Flow	Full Size Relays	Half Size Relays
Poiseuille	0.080 ± 0.008	0.070 ± 0.011
Slip	0.234 ± 0.033	0.466 ± 0.180
Molecular	0.313 ± 0.025	0 328 ± 0.035

To illustrate the correlation obtained by the two methods, Appendix Tables D1 and D2 were prepared. Listed there are the leak rates by RAG testing in one column followed by another column containing the leak rates by the HMS method which have been multiplied by the experimentally determined leak rate ratios, R. It is apparent from these data that the correlation in most cases was very good.

It should be emphasized that a single RAG test will yield the true leak rate only if the flow is molecular in character and only if the molecular flow equation is utilized. If the flow is not molecular, and this is possible; a single RAG test will not give the true leak rate. Only by repetitive testing at different pressures can the leak rate be determined accurately. If, however, the leak rate is desired to within an order of magnitude, a single RAG test may be performed if the molecular flow mechanism is assumed.

The failure of transistors because of leak weakening and breaking when exposed to a salt fog environment suggests the desirability of requiring either a humidity test or salt fog test as part of the lot sampling specifications required in the qualification of vendors. It is recognized, however, that if conformal coating is used, then humidity and salt fog environments will probably not affect a transistor so encased.

Two unique life testers were designed and constructed for this project. Each subjected the test components to severe operating conditions not usually found in comparable life testers.

APPENDICES

APPENDIX A

LIFE TEST RESULTS FOR RELAYS

Table A1. Full Size Relays Which Failed Due to Low Resistance Between Pins and Case (Bench Test)

Relay No.	Initial Failure	Failure After 10,000 Cycles	Failure After 110,222 Cycles	Failure After 180,000 Cycles
239 C		x		
106 C				x
163 C	x			
63 C		x		
185 C		x		
38 C				x
175 C				x
211 C	x			
117 C	x			
272 C	x			
259 C	x			
204 C		x		
195 C				
170 C				x
99 C				x
135 C				x
192 C		x		
95 C				x
60 C				x
229 C		x		
267 T				x
158 T	x			
115 T		x		
286 T		x		
118 T		x		
61 T		x		
111 T		x		
75 T		x		
71 T				x
188 T		x		
233 T		x		
100 T				x
54 T		x		
178 T				x
217 T	x			
265 T		x		
65 T	x			
83 T	x			
230 T	x			
263 T	x			
46 T				x
123 T	x			

Table A1. (Con't.)

Relay No.	Initial Failure	Failure After 10,000 Cycles	Failure After 110,222 Cycles	Failure After 180,000 Cycles
218 T		x		
73 T	x			
262 T		x		
284 T	x			
165 T				x
11 T				x
40 T		x		
280 T		x		
19 T	x			
288 T				x
234 T				x
18 T	x			
258 T		x		
248 T	x			
62 T	x			
145 T		x		
76 T		x		
222 T		x		
207 T		x		
154 T		x		
146 T		x		
82 T	x			
138 T		x		
290 T				x
53 T	x			
104 T		x		
177 T		x		
80 T				x
Totals:				
C	5	6	1	8
T	15	24	0	11
TOTAL	20	30	1	19

T = Test Group; C = Control Group.

Table A2 . Half Size Relays Which Failed Due to Low Resistance Between Pins and Case (Bench Test)

Relay No.	Initial Failure	Failure After 10,000 Cycles	Failure After 110,000 Cycles	Failure After 210,000 Cycles	Failure After 310,000 Cycles
75 T	x				
162 T	x				
116 T	x				
15 T	x				
53 T	x				
138 T	x				
234 T	x				
250 T	x				
178 T	x				
146 T	x				
150 T	x				
46 T	x				
315 T			x		
104 T				x	
X T				x	
18 T					x
103 T					x
52 C	x				
172 C	x				
198 C	x				
189 C		x			
299 C		x			
30 C					x
Totals:					
T	12	0	1	2	2
C	3	2	0	0	1
TOTALS	15	2	1	2	3

Total Relays bench tested were 240.
T = Test Group; C = Control Group

Table A3. Full Size Relays with Leak Rates in the Range 2 X 10^{-7} to 2 X 10^{-5} cc/sec. Times to Failure of Test Group.

Relay No.	Cycles to Failure	Relay No.	Cycles to Failure
287	36,403	53	118,759
46	59,512	223	119,204
230	61,506	189	120,232
102	67,553	37	125,330
89	82,406	1	140,059
290	82,686	138	141,852
158	88,573	217	143,060
118	91,883	178	143,725
262	94,455	7	146,441
94	98,974	11	146,609
215	100,333	62	149,961
238	103,040	104	151,536
276	105,875	143	153,037
207	108,743	43	172,699
221	112,714	226	173,002
224	116,209	222	173,115

Relays 278 and 46 were considered to be early failures.

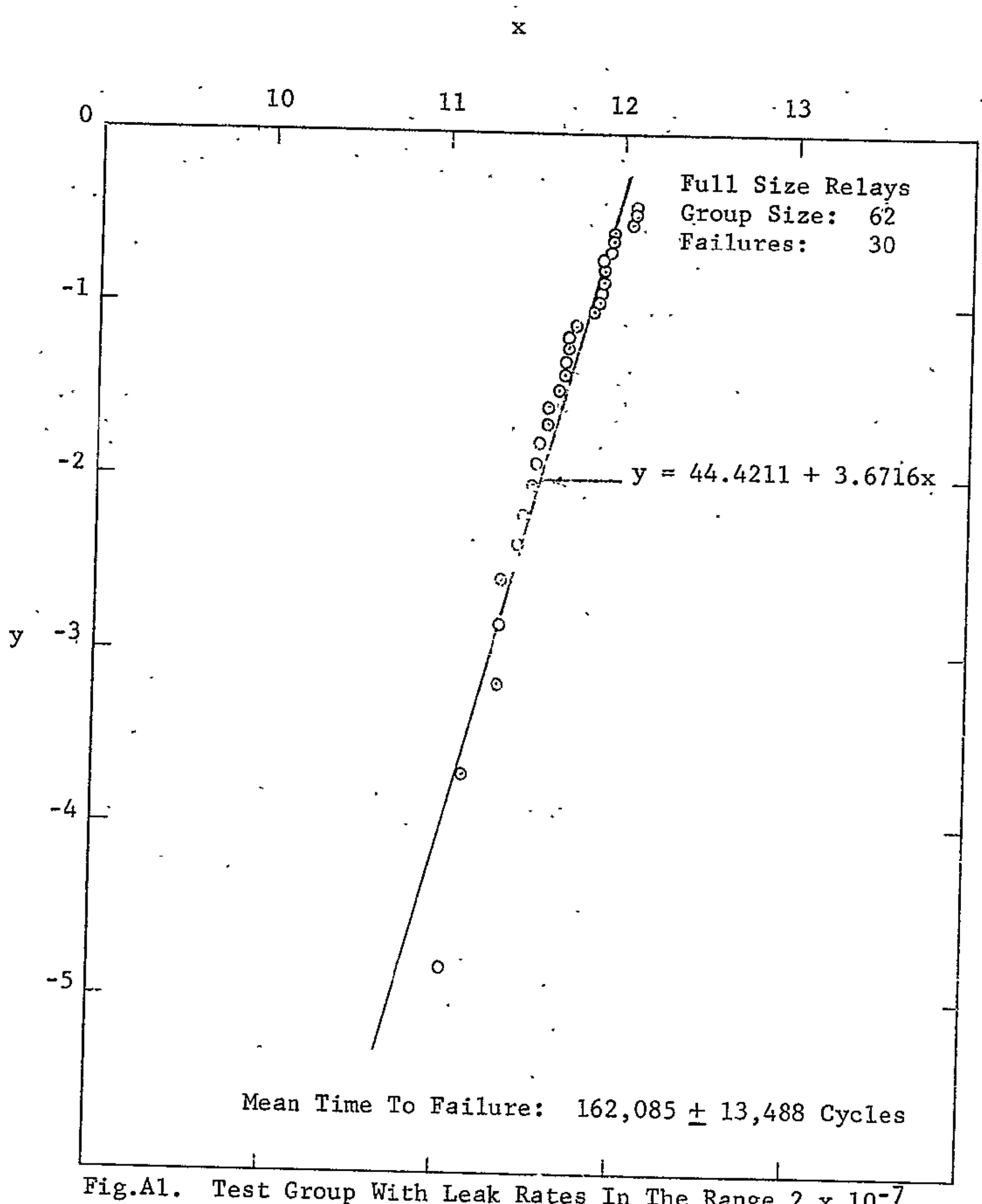

Fig.A1. Test Group With Leak Rates In The Range 2×10^{-7} to 2×10^{-5} cc/sec.

Table A4. Full Size Relays With Leak Rates in the Range 2 X 10^{-7} to 2 X 10^{-5} cc/sec. Times to Failure of Control Group.

Relay No.	Cycles to Failure	Relay No.	Cycles to Failure
103	41,443	23	127,972
281	47,617	105	131,791
185	73,986	74	134,764
235	81,559	192	135,287
20	83,345	208	136,394
166	87,585	63	138,202
170	89,349	175	144,074
231	92,748	260	148,861
121	99,362	130	151,828
209	100,838	86	161,065
164	102,338	239	163,275
149	102,902	237	164,925
199	111,948	9	166,309
32	114,204	90	167,084
241	117,645	282	172,091
64	118,344	108	176,549
202	118,483	126	178,060
15	127,720		

Relays 103 and 281 were considered to be early failures.

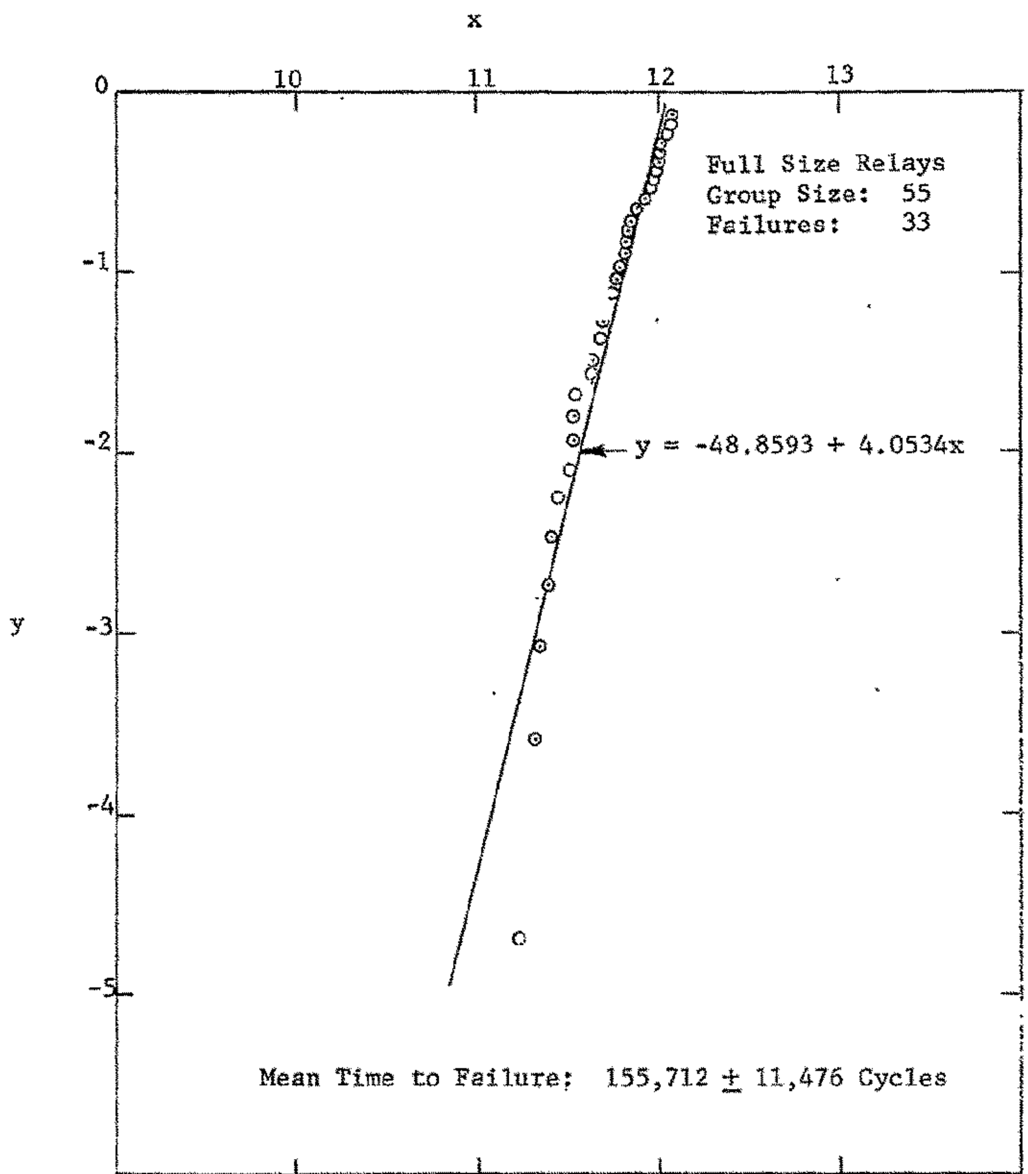

Fig.A2. Control Group With Leak Rates In The Range 2 x 10^{-7} to 2 x 10^{-5} cc/sec.

Table A5. Full Size Relays with Leak Rates Less than 2 X 10^{-7} cc/sec. Times to Failure of Test Group.

Relay No.	Cycles to Failure	Relay No.	Cycles to Failure
141	38,489	258	117,636
80	56,490	172	119,377
279	61,110	65	121,617
265	75,950	253	122,539
54	83,550	165	125,329
40	90,740	61	127,107
267	92,740	19	131,383
248	96,905	154	132,209
67	97,625	2	132,725
234	102,565	167	146,606
284	110,471	203	163,368
295	113,476	245	163,817
288	116,686	100	176,543
191	116,944	110	177,232

Relays 141 and 80 were considered to be early failures.

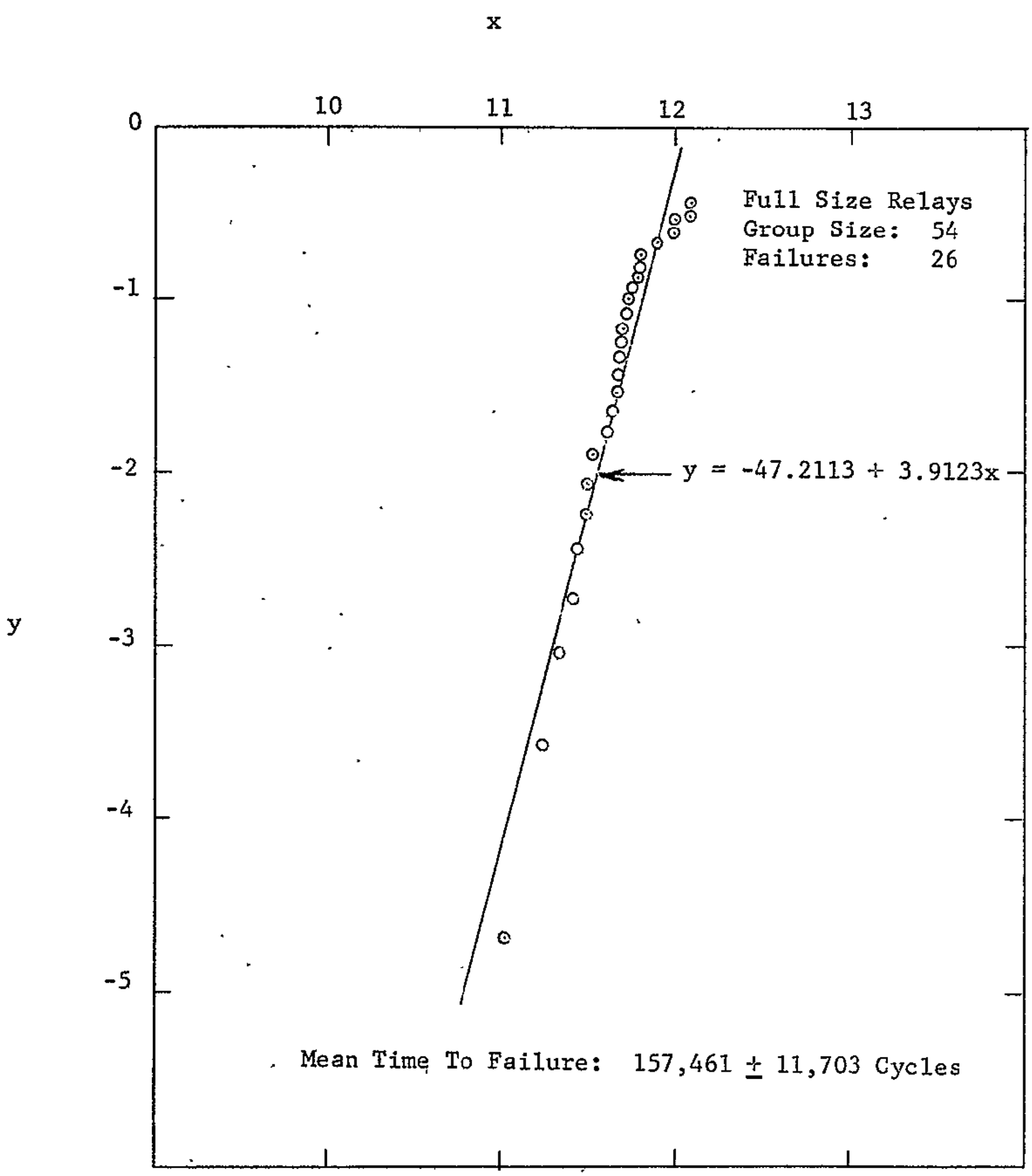

Fig.A3. Test Group With Leak Rates Less Than 2 x 10^{-7} cc/sec.

Table A6. Full Size Relays With Leak Rates Less than 2 X 10^{-7} cc/sec. Times to Failure of Control Group.

Relay No.	Cycles to Failure	Relay No.	Cycles to Failure
174	36,030	72	116,482
257	38,788	274	117,393
270	45,743	55	118,006
99	49,598	50	122,904
232	57,518	135	128,507
159	57,524	228	128,929
58	62,780	4	144,050
289	65,832	268	147,022
36	69,679	275	147,451
247	87,042	152	149,197
283	88,587	173	152,114
251	97,559	261	173,770
44	100,277	95	179,296
243	110,492		

Relays 174, 257, 270, 99, 232, and 159 were considered to be early failures.

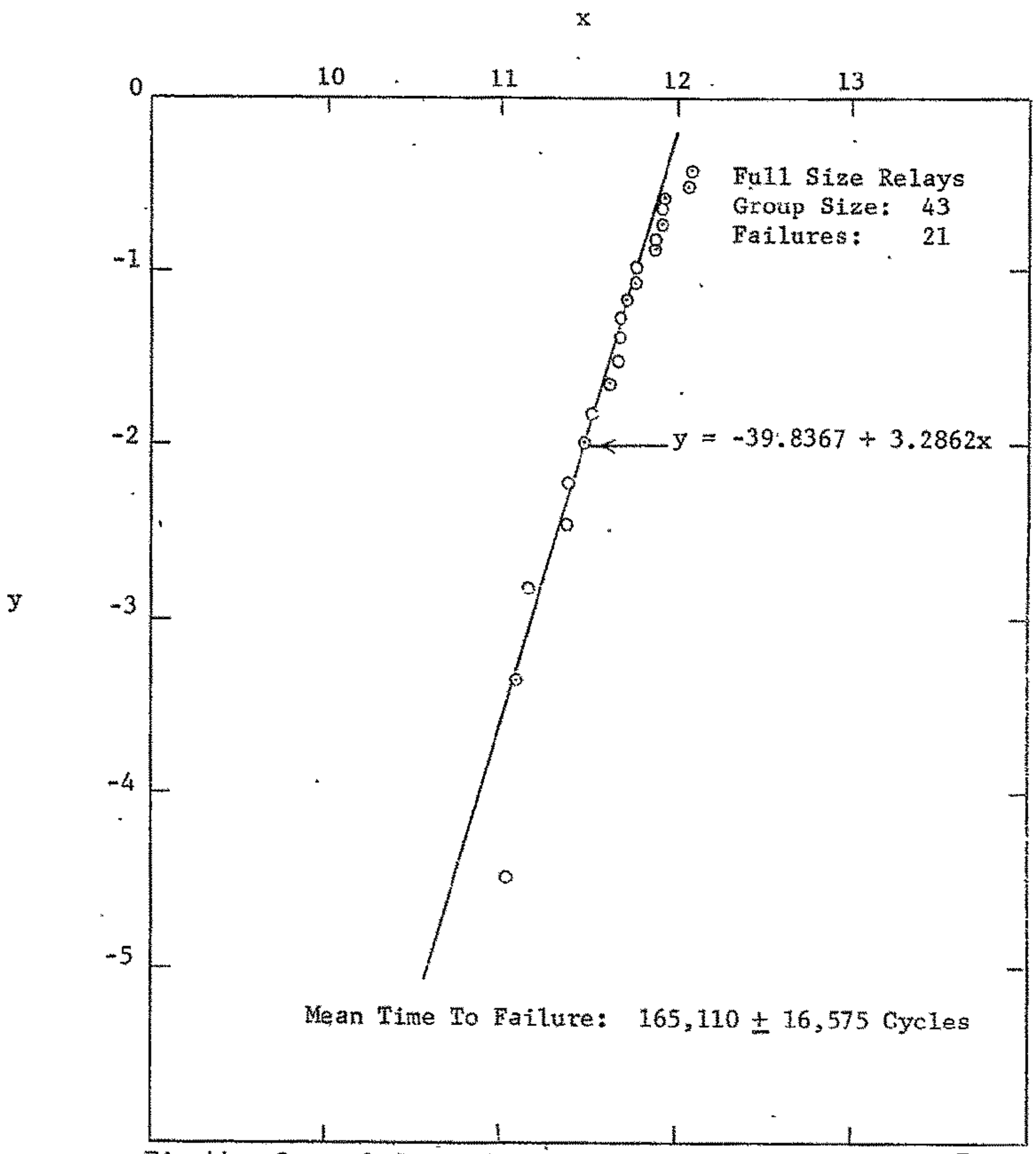

Fig.A4. Control Group With Leak Rates Less Than 2 x 10^{-7} cc/sec.

Table A7. Half Size Relays with Leak Rates in the Range 2 X 10^{-8} to 2 X 10^{-5} cc/sec. Times to Failure of Test Group.

Relay No.	Cycles to Failure
76	10,016
77	26,427
314	35,318
209	53,312
152	190,530
61	227,323
162	231,043
160	239,845
114	245,181
38	290,899
44	299,070
35	310,377
278	311,352
49	321,192
222	321,671
244	322,169
103	335,392

Relays 76, 77, 314, and 209 were considered to be early failures.

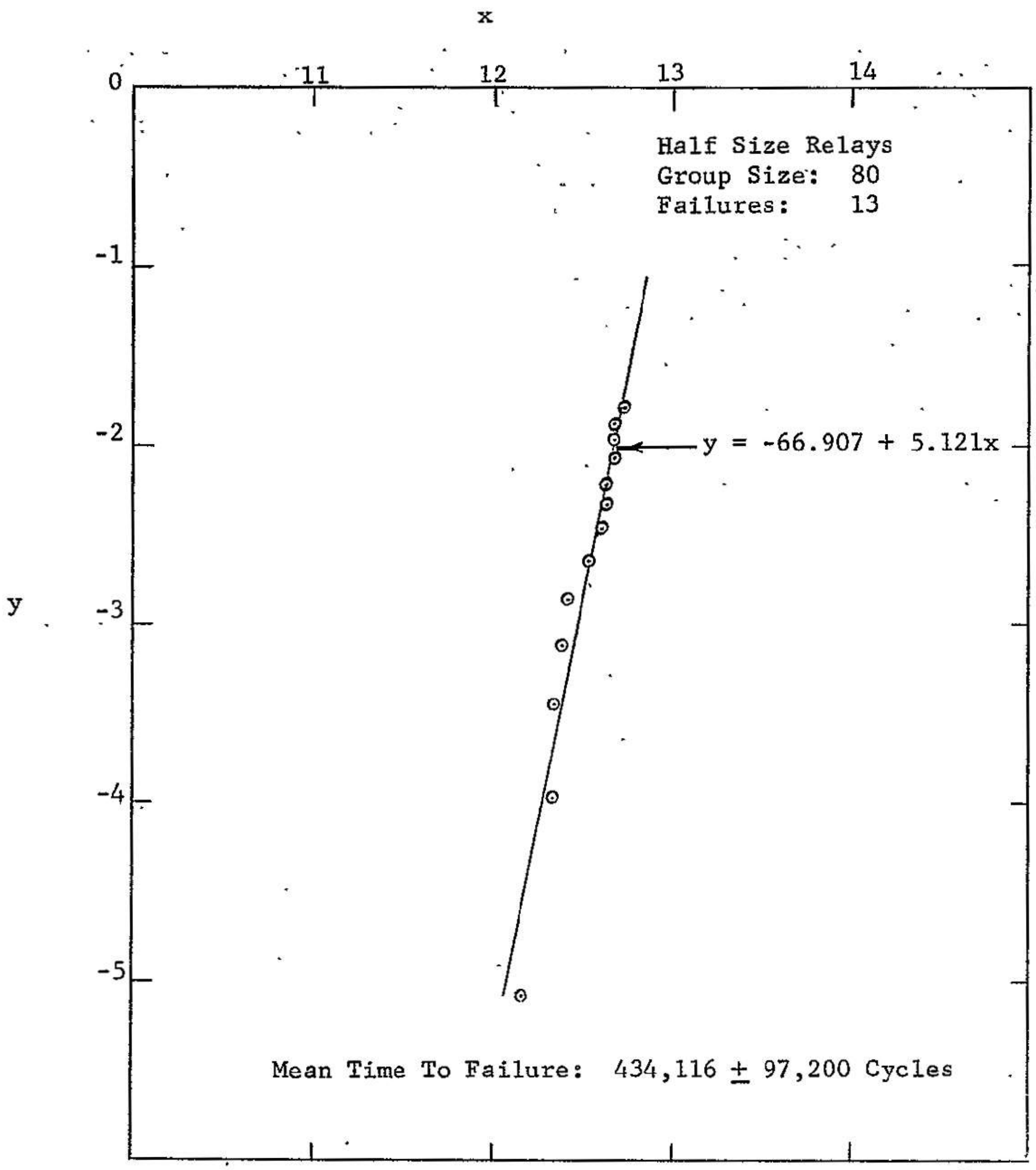

Fig.A5. Test Group With Leak Rates In The Range 2×10^{-8} to 2×10^{-5} cc/sec.

Table A8. Half Size Relays With Leak Rates in the Range 2 X 10^{-8} to 2 X 10^{-5}. Times to Failure of the Control Group.

Relay No.	Cycles to Failure
126	10,000
136	10,000
184	13,437
317	32,675
62	118,742
171	323,459
179	329,298
52	332,426
41	338,602
20	355,557

Relays 126, 136, 184, 317, and 62 were considered to be early failures.

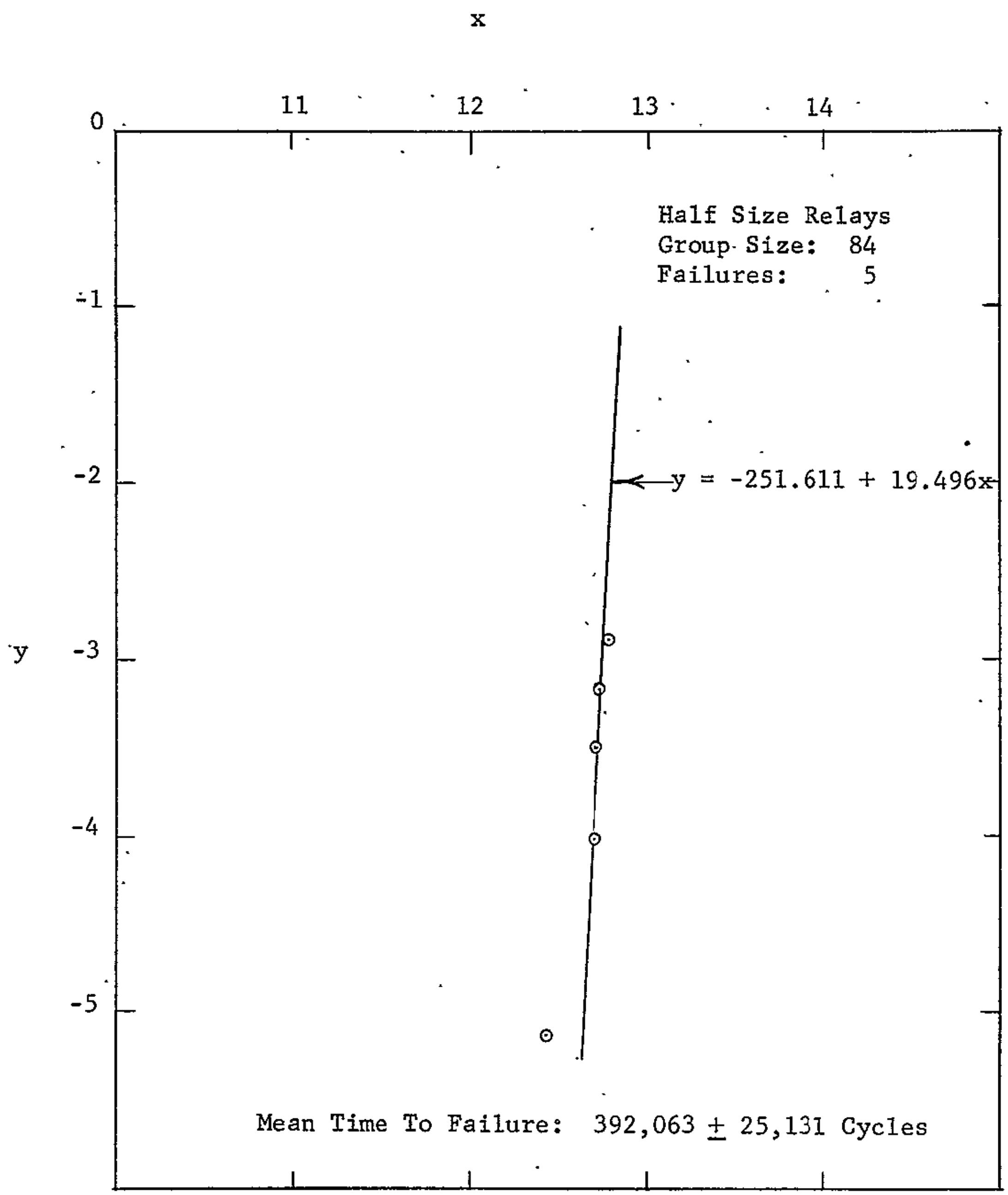

Fig.A6. Control Group With Leak Rates In The Range 2×10^{-8} to 2×10^{-5} cc/sec.

Table A9. Half Size Relays With Leak Rates Less Than 2 X 10^{-8} cc/sec. Times to Failure of the Test Group.

Relay No.	Cycles to F
197	102,739
16	103,010
23	223,375
216	254,978
115	275,549
71	311,085
208	314,240
144	321,144
132	326,792
187	332,434
90	332,548
X	335,579

Relays 197 and 16 were considered to be early failures.

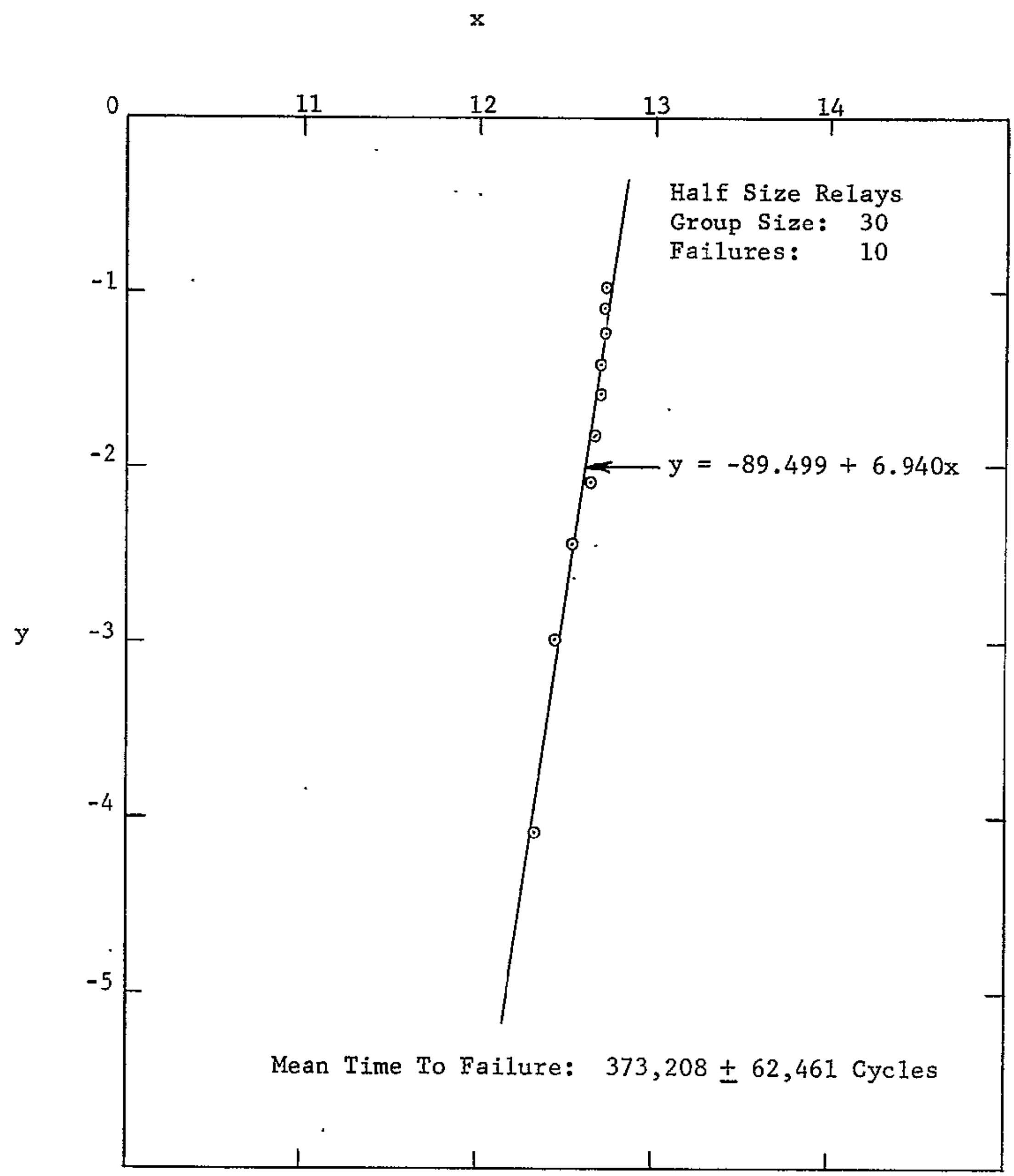

Fig. A7. Test Group With Leak Rates Less Than 2 x 10^{-8} cc/sec.

Table A10. Half Size Relays With Leak Rates Less Than 2 X 10^{-8} cc/sec. Times to Failure of the Control Group.

Relay No.	Cycles to Failure
189	10,102
270	11,362
165	59,289
196	213,577
158	218,379
66	312,379
22	323,485
214	350,636

Relays 189, 270, and 165 were considered to be early failures.

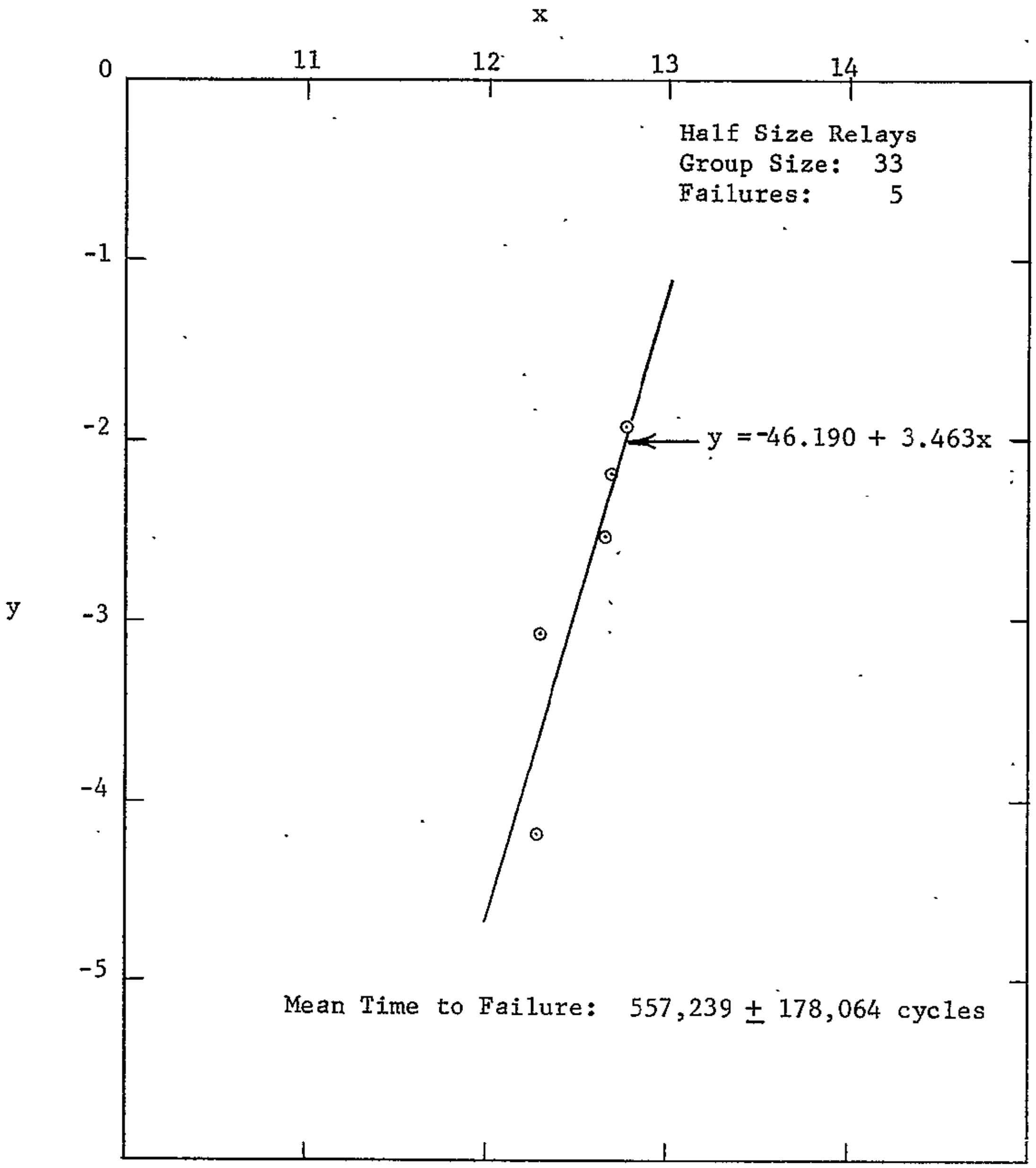

Fig. A8. Control Group With Leak Rates Less Than 2 x 10^{-8} cc/sec.

Table A11. Full Size Relays With Leak Rates Between 2 X 10^{-9} cc/sec. and 2 X 10^{-8} cc/sec. Times to Failure of the Test Group.

Relay No.	Cycles to Failure
279	61,110
172	119,377
65	121,617
165	125,329
19	131,383

Relay 279 was considered to be an early failure.

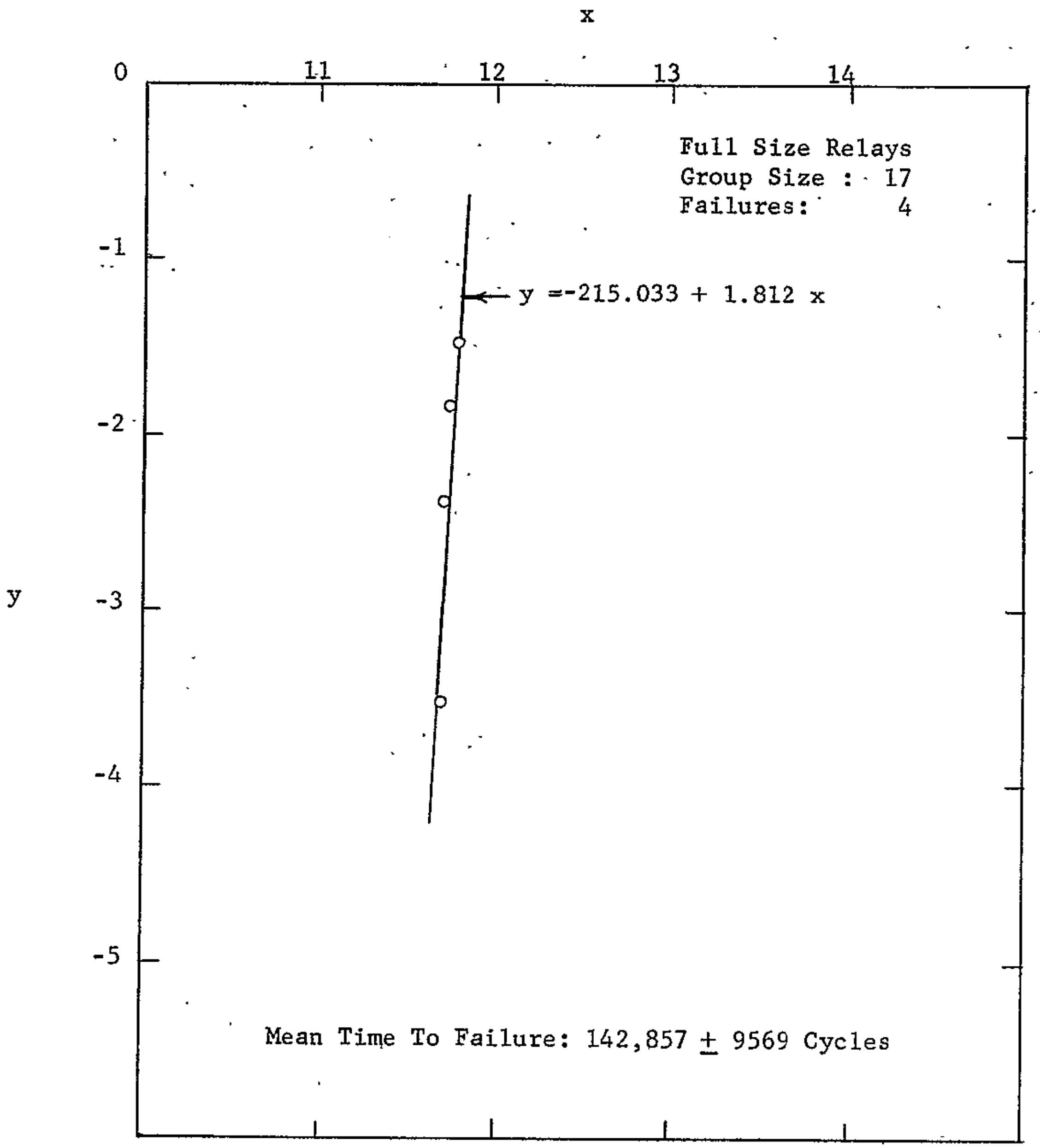

Fig. A9. Test Group With Leak Rates From 2 x 10^{-9} cc/sec. to 2 x 10^{-8} cc/sec.

Table A12. Full Size Relays With Leak Rates Between 2 X 10^{-9} cc/sec. and 2 X 10^{-8} cc/sec. Times to Failure of the Control Group.

Relay No.	Cycles to Failure
257	38,788
232	57,518
58	62,780
36	69,679
247	87,042
44	100,277
55	118,006
95	179,296

Relays 257 and 232 were considered to be early failures. Relays 95 was arbitrarily omitted due to inconsistency with other data.

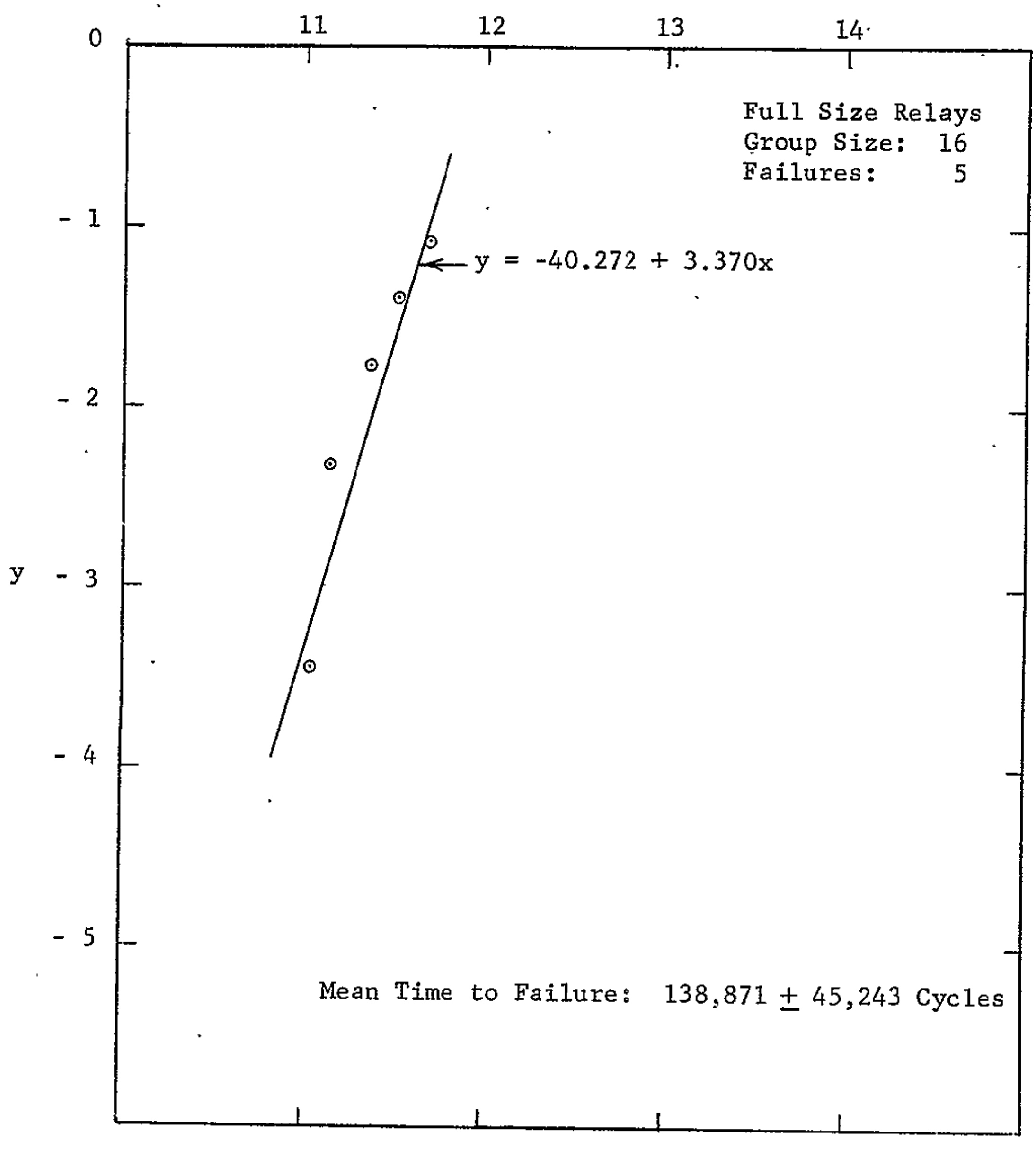

Fig. A10. Control Group With Leak Rates From 2 x 10^{-9} cc/sec. to 2 x 10^{-8} cc/sec.

Table A13. Full Size Relays With Leak Rates Between 2×10^{-8} cc/sec. and 2×10^{-7} cc/sec. Time to Failure of the Test Group.

Relay No.	Cycles to Failure
141	38,489
54	83,550
40	90,740
267	92,740
248	96,905
67	97,625
234	102,565
284	110,471
295	113,476
288	116,686
191	116,944
258	117,636
61	127,107
154	132,209
2	132,725
167	146,606
203	163,368
245	163,817
110	177,232

Relay 141 was considered to be an early failure. Relay 203, 245, and 110 were arbitrarily omitted due to inconsistency with other data.

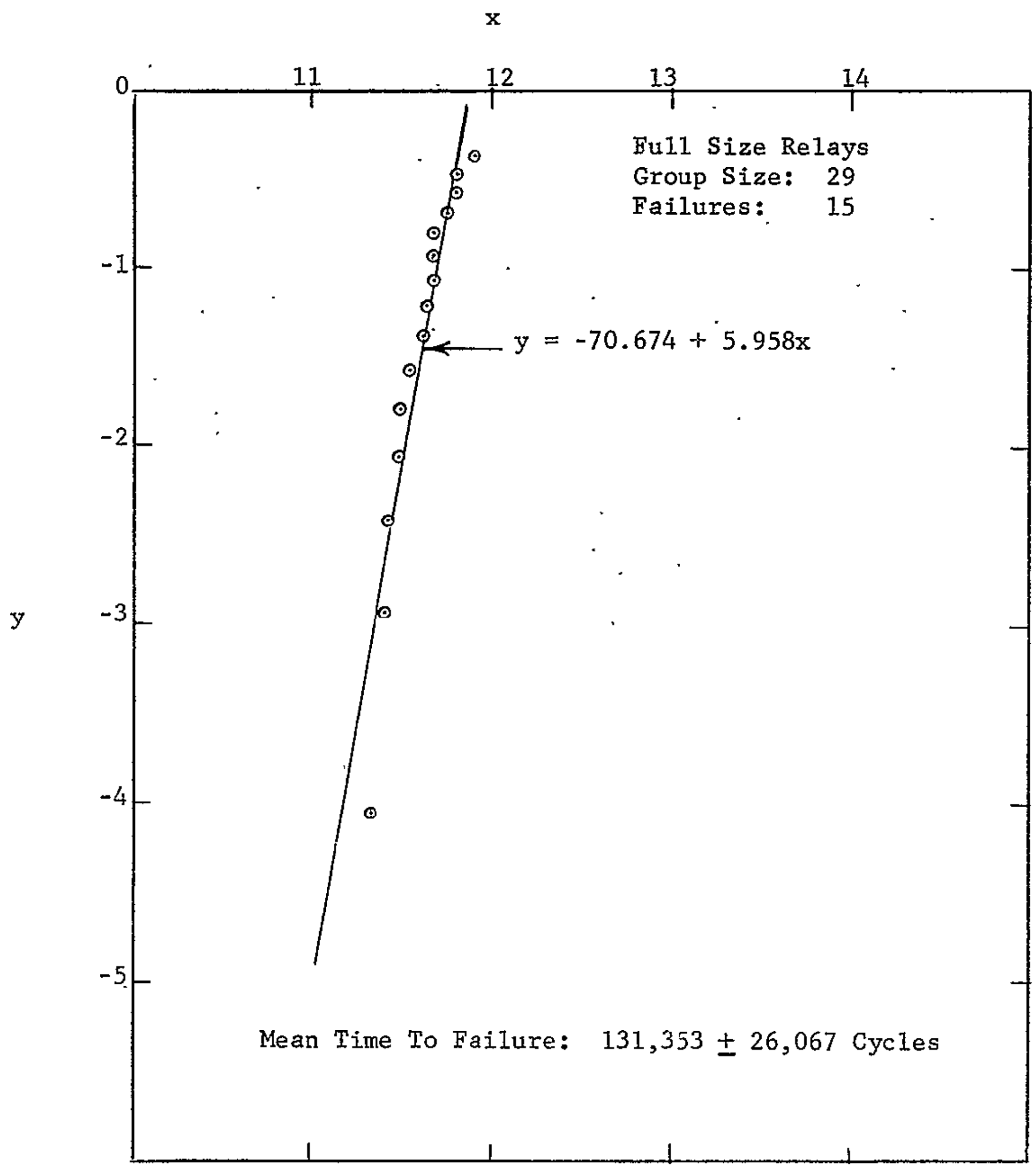

Fig.A11. Test Group With Leak Rates From 2 x 10^{-8} cc/sec. to 2 x 10^{-7} cc/sec.

Table A14. Full Size Relays With Leak Rates Between 2 X 10^{-8} cc/sec. and 2 X 10^{-7} cc/sec. Times to Failure of the Control Group

Relay No.	Cycles to Failure
174	36,030
270	45,743
159	57,524
283	88,587
251	97,559
243	110,492
274	111,393
50	122,539
135	128,507
228	128,929
4	144,050
268	147,022
275	147,451
152	149,197
227	166,899
261	173,770

Relays 174, 270, and 159 were considered to be early failures. Relays 227 and 261 were arbitrarily omitted due to inconsistency with other data.

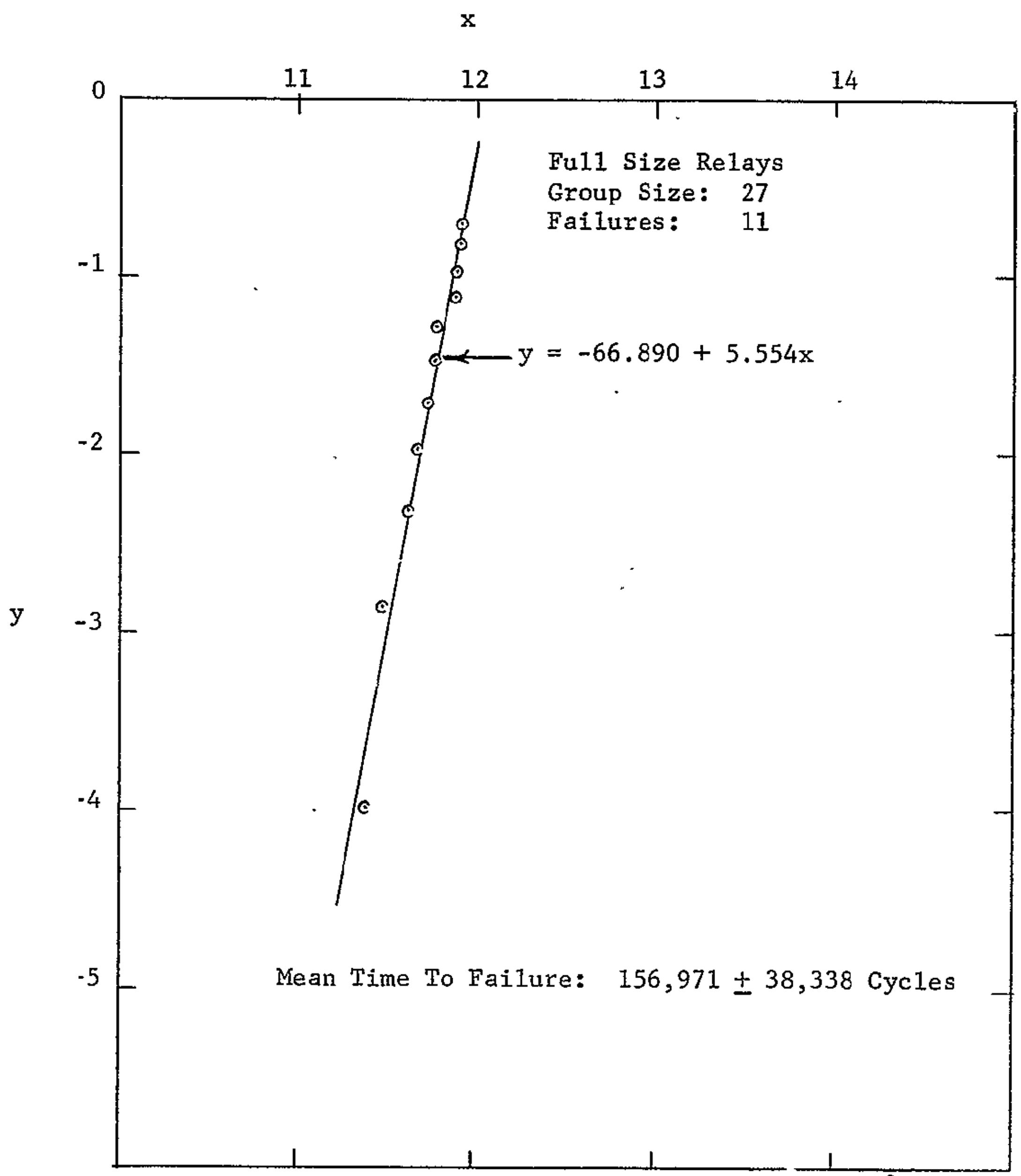

Fig.A12. Control Group With Leak Rates From 2 x 10^{-8} cc/sec to 2 x 10^{-7} cc/sec.

Table A15. Full Size Relays With Leak Rates Between 2 X 10^{-7} cc/sec. and 2 X 10^{-6} cc/sec. Times to Failure of the Test Group

Relay No.	Cycles to Failure
278	36,403
230	61,506
102	67,553
290	82,686
262	94,455
94	98,974
215	100,333
238	103,040
276	105,875
207	108,743
221	112,714
53	118,759
189	120,232
217	143,060
7	146,441
11	146,609
62	149,961
226	173,002

Relay 278 was considered to be an early failure.
Relay 226 was arbitrarily omitted due to inconsistency with other data.

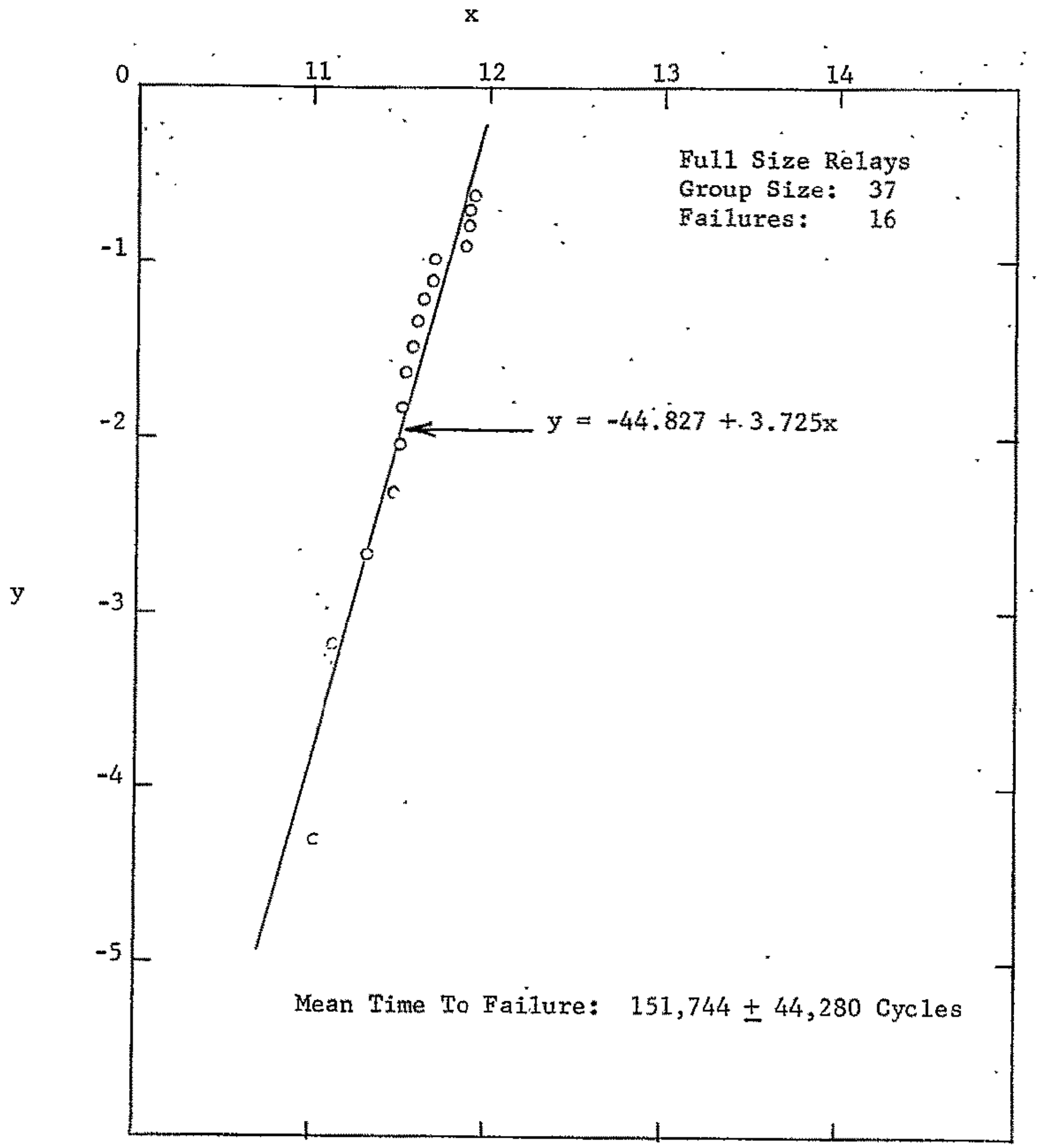

Fig.A13. Test Group With Leak Rates From 2×10^{-7} cc/sec. to 2×10^{-6} cc/sec.

Table A16. Full Size Relays With Leak Rates Between 2 X 10^{-7} cc/sec. and 2 X 10^{-6} cc/sec. Times to Failure of the Control Group.

Relay No.	Cycles to Failure
103	41,443
281	47,617
185	73,986
235	81,559
166	87,585
231	92,748
121	99,362
164	102,338
199	111,948
32	114,204
241	117,645
64	118,344
202	118,483
15	127,720
23	127,972
105	131,791
192	135,287
208	136,394
175	144,074
260	148,861
239	163,275
237	164,925
9	166,309
282	172,091

Relays 103 and 281 were considered to be early failures. Relays 239, 237, 9, and 282 were arbitrarily omitted due to inconsistency with other data.

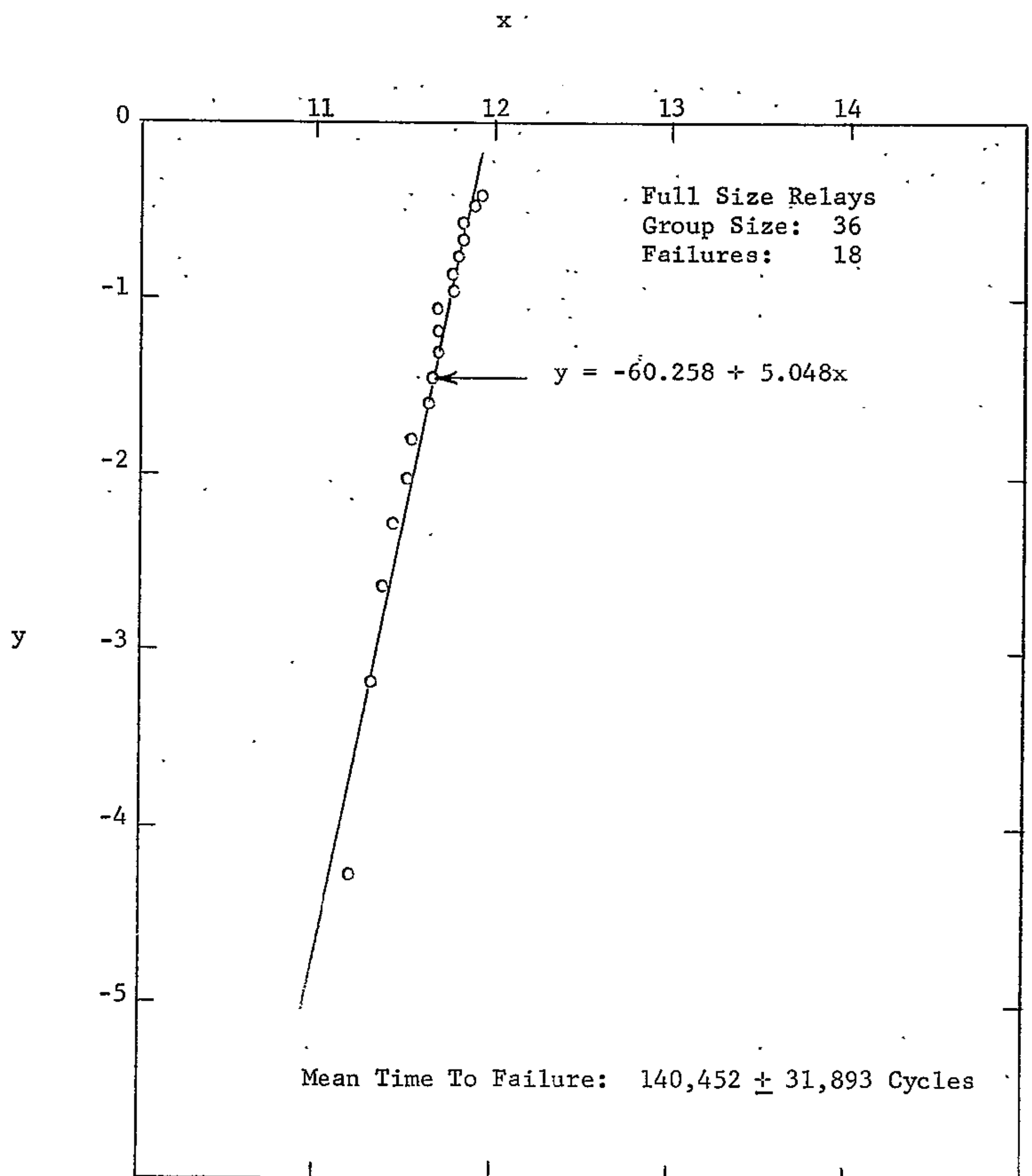

Fig.A14. Control Group With Leak Rates From 2 x 10^{-7} cc/sec. to 2 x 10^{-6} cc/sec.

Table A17. Full Size Relays With Leak Rates Between 2×10^{-6} cc/sec. and 2×10^{-5} cc/sec. Times To Failure of the Test Group.

Relay No.	Cycles to Failure
46	59,512
89	82,406
158	88,573
118	91,883
71	110,593
224	116,209
223	119,204
37	125,330
111	130,537
1	140,059
178	143,725
133	144,415
143	153,037
43	172,699
222	173,115

Relay 46 was considered to be an early failure.
Relay 43 and 222 were arbitrarily omitted due to inconsistency with other data.

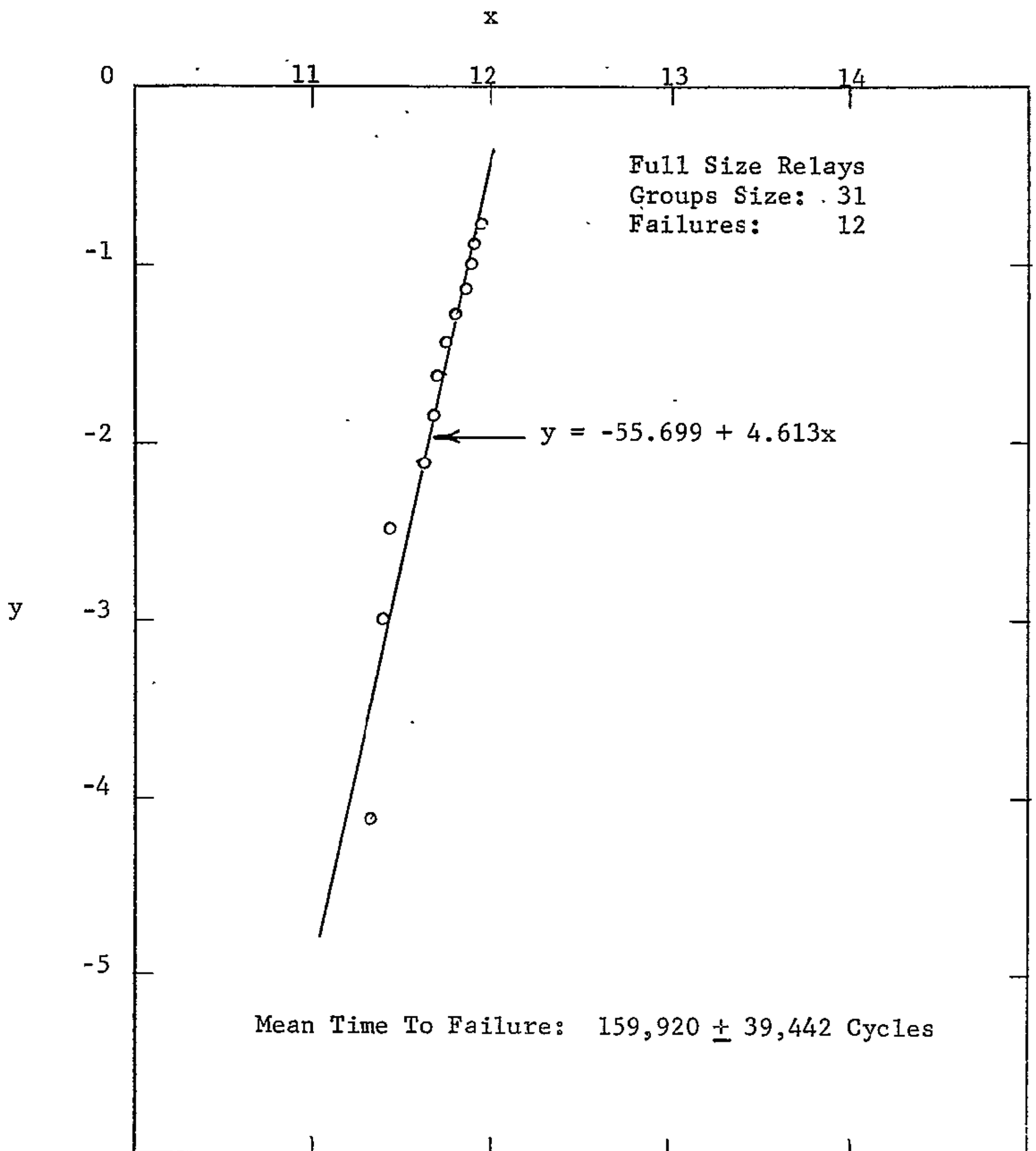

Fig.A15. Test Group With Leak Rates From 2 x 10^{-6} cc/sec. to 2 x 10^{-5} cc/sec.

Table A18. Full Size Relay With Leak Rates Between 2 X 10^{-6} cc/sec. and 2 X 10^{-5} cc/sec. Times to Failure of the Control Group.

Relay No.	Cycles to Failure
20	83,345
170	89,349
209	100,838
149	102,902
39	132,118
74	134,764
63	138,202
130	151,828
90	167,084
150	172,374
124	175,081
108	176,549

Relay 90, 150, 124, and 108 were arbitrarily omitted due to inconsistency with other data.

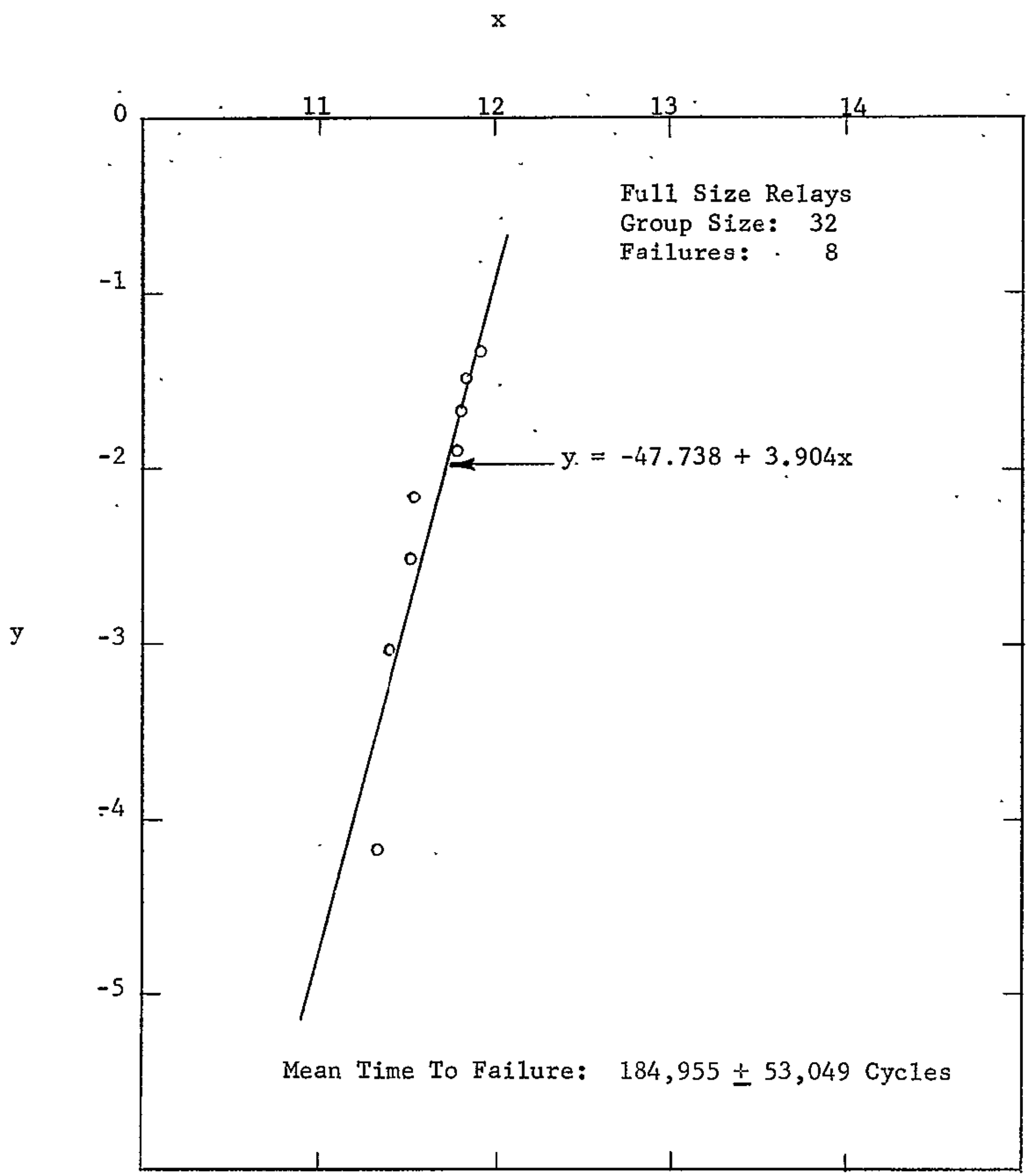

Fig.A16. Control Group With Leak Rates From 2 x 10^{-6} cc/sec. to 2 x 10^{-5} cc/sec.

Table A19. Full Size Relays Which Failed and Causes of Failure.

		Cause of Failure			
Relay No.	Cycles to Failure	Miss	Weld or Bridge	Arc to Case	Contact Resistance
174	36,030				x
278	36,403				x
141	38,489				x
257	38,788	x			
103	41,443				x
270	45,743				x
281	47,617				x
99	49,598				x
80	56,490				x
232	57,518	x			
159	57,524				x
232*	59,422				x
46	59,512				x
279	61,110				x
230	61,506				x
58	62,780				x
289	65,832	x			
102	67,553				x
36	69,679				x
185	73,986		x		
265	75,950				x
235	81,559				x
89	82,406				x
290	82,686				x
20	83,345				x
54	83,550				x
289*	84,634				x
247	87,042				x
166	87,585				x
159*	87,826				x
158	88,573				x
283	88,587				x
170	89,349				x
40	90,740				x
118	91,883				x
267	92,740				x
231	92,748				x
262	94,455				x
248	96,905				x
251	97,559				x
67	97,625		x		
94	98,974				x
121	99,362				x
44	100,277				x
215	100,333				x
209	100,839				x

Table A19. (Con't.)

Relay No.	Cycles to Failure	Cause of Failure			
		Miss	Weld or Bridge	Arc to Case	Contact Resistance
164	102,338				x
234	102,565				x
149	102,902				x
238	103,040				x
276	105,875				x
207	108,743				x
284	110,471				x
243	110,492				x
71	110,593				x
199	111,948				x
144	112,001		x		
232*	112,533		x		
215*	112,665				x
221	112,714	x			
295	113,476				x
32	114,204				x
224	116,209				x
72	116,482				x
288	116,686				x
191	116,944				x
274	117,393				x
258	117,686				x
241	117,645				x
55	118,006				x
64	118,344				x
202	118,483				x
53	118,759				x
223	119,204				x
172	119,377				x
189	120,232				x
46*	120,234				x
65	121,617				x
253	122,539				x
50	122,904				x
165	125,329				x
37	123,330				x
61	127,107				x
15	127,720				x
23	127,972				x
135	128,507				x
135*	128,747				x
228	128,929				x
284	129,937				x
111	130,537				x
103	130,716				x
19	131,138				x
105	131,791				x

Table A19. (Con't.)

Relay No.	Cycles to Failure	Cause of Failure: Miss	Weld or Bridge	Arc to Case	Contact Resistance
39	132,118				x
154	132,209				x
2	132,725				x
164*	133,838				x
74	134,764				x
192	135,287				x
283*	135,905				x
284*	136,394				x
208	138,073				x
63	138,202				x
290*	139,943				x
1	140,059				x
99*	141,767				x
138	141,852				x
54	141,997				x
40*	142,849				x
217	143,060				x
286	143,128		x		
178	143,725				x
4	144,050				x
175	144,074				x
103*	144,075		x		
133	144,415				x
7	146,441				x
167	146,606				x
110	146,609				x
268	147,022				x
275	147,451				x
260	148,861				x
152	149,197				x
62	149,961				x
278	150,946				x
104	151,836				x
130	151,828				x
173	152,114				x
143	153,037				x
80*	155,961				x
170*	155,976				x
53*	156,632				x
86	161,065				x
239	163,275				x
203	163,368				x
165*	163,534				x
245	163,817				x
158*	164,814				x
237	164,925				x
9	166,309				x
227	166,899				x

Table A19. (Con't.)

Relay No.	Cycle to Failure	Cause of Failure: Miss	Weld or Bridge	Arc to Case	Contact Resistance
90	167,084				x
111*	169,218				x
256	171,026				x
267*	171,123				x
282	172,091				x
9*	172,270				x
150	172,374				x
43	172,699				x
226	173,002				x
222	173,115				x
261	173,770				x
124	175,081				x
100	176,543				
108	176,549				x
110*	177,232				x
100*	177,232		x		x
126	178,060				x
71*	178,548				x
175*	179,108				x
288	179,121				x
95	179,296				x
Totals (Failures for the first time)		4	4		128

* Relay previously failed and turned over to use new set of contacts failed again.

Table A20. Half Size Relays Which Failed and Causes of Failure

Relay No.	Cycles to Failure	Cause of Failure: Miss	Weld or Bridge	Arc to Case	Contact Resistance
126	10,000		X		
136	10,000		X		
76	10,016				X
189	10,102				X
270	11,362				X
184	13,437			X	
77	26,427				X
317	32,675				X
314	35,318				X
209	53,312				X
165	59,289				X
254	62,600	X			
197	102,739				X
16	103,010				X
197*	103,737				X
136*	110,050	X			
62	118,742				X
165*	119,111	X			
152	190,530				X
196	213,577				X
158	218,379				X
23	223,375				X
61	227,323				X
162	231,043				X
160	239,845				X
114	245,181				X
216	254,978				X
115	275,549				X
38	290,899				X
44	299,070				X
35	310,377				X
71	311,085	X			
278	311,352	X			
66	312,379				X
208	314,240				X
144	321,144				X
49	321,192				X
222	321,671				X
66*	321,899				X
244	322,169				X
171	323,459				X
22	323,485				X
132	326,792	X			
179	329,298	X			
126*	331,292	X			
52	332,426		X		
187	332,434				X

Table A20. (Con't.)

Relay No.	Cycles to Failure	Miss	Weld or Bridge	Arc to Case	Contact Resistance
		Cause of Failure			
52	332,436		X		
90	332,548				X
103	335,392	X			
X	335,579				X
41	338,602				X
214	350,636				X
20	355,557				X
Totals (Failures for the first time)		6	3	1	38

*Relay previously failed and turned over to use new set of contacts failed again.

APPENDIX B

RAG-HMS RESULTS

Table B1 . RAG and HMS Leak Rates for Full Size Relays

Relay No.	Flow	Q_s^R(atm.cc/sec) (RAG)	Q_s^{MS}(atm.cc/sec) (HMS)	$R=Q_s^R/Q_s^{MS} \pm \sigma$
1	M	(8.36 ± 0.21)x10-7	3.80 x 10-6	.220 $\pm$ .103
2	M	(3.60 ± 0.29)x10-8	7.80 x 10-8	.462 $\pm$ .129
4			4.10 x 10-8	
7	M	(2.39 ± 0.11)x10-7	8.50 x 10-7	.282 $\pm$ .110
8			2.50 x 10-8	
9			4.20 x 10-7	
11	M	(4.45 ± 0.26)x10-8	2.06 x 10-7	.216 $\pm$ .116
12			5.50 x 10-9	
14	M	(4.21 ± 0.26)x10-8	1.30 x 10-7	.324 $\pm$ .118
15	M	(9.60 ± 1.07)x10-8	9.20 x 10-7	.104 $\pm$ .149
17			4.00 x 10-9	
18			3.00 x 10-8	
19			1.55 x 10-8	
20	S	(8.90 ± 0.34)x10-7	5.60 x 10-6	.159 $\pm$ .107
21	P	(8.19 ± 0.08)x10-7	9.80 x 10-6	.084 $\pm$ .101
22			3.10 x 10-8	
23	P	(6.69 ± 0.43)x10-8	1.20 x 10-6	.056 $\pm$ .119
26			6.90 x 10-8	
27	S	(9.38 ± 0.34)x10-7	1.06 x 10-5	.088 $\pm$ .106
29			7.30 x 10-9	
31			4.00 x 10-8	
32	M	(1.12 ± 0.11)x10-8	6.50 x 10-7	.172 $\pm$ .138
33			5.50 x 10-9	
34			1.70 x 10-6	
35			1.10 x 10-8	
36			9.50 x 10-9	
37	S	(3.03 ± 0.22)x10-7	2.03 x 10-6	.149 $\pm$ .123
38	M	(6.95 ± 0.21)x10-7	4.00 x 10-6	.174 $\pm$ .105
39	S	$(1.63 \pm .003)$x10-6	1.26 x 10-5	.129 $\pm$ .102
40			1.01 x 10-7	
41			1.40 x 10-7	
42			1.65 x 10-8	
43	M	(1.97 ± 0.03)x10-6	7.00 x 10-6	.281 $\pm$ .102
44			4.57 x 10-7	
46	M	(5.50 ± 0.21)x10-7	2.30 x 10-6	.239 $\pm$ .107
47	P	(1.05 ± 0.01)x10-6	1.60 x 10-5	.095 $\pm$ .100
48	M	(1.42 ± 0.34)x10-8	1.70 x 10-7	.083 $\pm$ .262
50			5.10 x 10-8	
51			7.00 x 10-9	
53			5.50 x 10-7	
54			2.70 x 10-8	
55			1.95 x 10-8	
56	P	(1.15 ± 0.01)x10-6	1.30 x 10-5	.089 $\pm$ .100
57			3.50 x 10-9	
58			2.10 x 10-9	
60			2.20 x 10-8	

Table B1 . (Con't.)

Relay No.	Flow	Q_s^R(atm.cc/sec) (RAG)	Q_s^{MS} (atm.cc/sec) (HMS)	$R=Q_s^R/Q_s^{MS} \pm \sigma$
61			1.25 x 10-7	
62	P	(3.46 ± 0.21)x10-8	9.80 x 10-7	.035 ± .118
63	S	(1.72 ± 0.04)x10-6	6.00 x 10-6	.286 ± .103
64	S	(2.29 ± 2.17)x10-8	1.10 x 10-6	.021 ± .953
65			4.00 x 10-9	
66			5.50 x 10-9	
67			2.65 x 10-8	
68			1.45 x 10-8	
69	M	(3.06 ± 0.04)x10-6	6.60 x 10-6	.464 ± .101
70	M	(5.80 ± 0.26)x10-8	1.40 x 10-7	.414 ± .110
71	P	(1.16 ± 0.01)x10-6	1.20 x 10-5	.096 ± .100
72			1.40 x 10-9	
73			1.65 x 10-8	
74	S	(8.59 ± 0.34)x10-7	5.50 x 10-6	.156 ± .107
75			2.90 x 10-8	
76	M	(5.69 ± 0.21)x10-7	1.72 x 10-6	.331 ± .107
77			2.00 x 10-5	
79			5.60 x 10-5	
80				
82	S	(1.67 ± 0.03)x10-6	1.10 x 10-5	.152 ± .102
83			2.80 x 10-8	
85			1.98 x 10-5	
86			6.90 x 10-5	
87			2.00 x 10-5	
88			4.40 x 10-5	
89	M	(4.21 ± 0.21)x10-7	4.40 x 10-6	.096 ± .112
90	M	(2.80 ± 0.21)x10-7	3.00 x 10-6	.093 ± .126
91	M	(6.98 ± 0.26)x10-8	2.70 x 10-7	.258 ± .107
92			3.20 x 10-5	
94	S	(1.57 ± 0.22)x10-7	1.01 x 10-6	.155 ± .171
95			1.10 x 10-8	
98			3.50 x 10-5	
99			1.00 x 10-9	
100			8.00 x 10-10	
101		(2.97 ± 3.29)x10-8	1.50 x 10-7	.198 ± 1.11
102	M	(9.47 ± 0.46)x10-8	2.50 x 10-7	.379 ± .111
103	M	(1.18 ± 0.25)x10-7	1.10 x 10-6	.107 ± .232
104			3.00 x 10-5	
105	M	(1.66 ± 0.11)x10-7	8.00 x 10-7	.207 ± .119
106			1.20 x 10-8	
107			1.80 x 10-9	
108	M	(3.60 ± 0.21)x10-7	3.40 x 10-6	.106 ± .116
110			6.20 x 10-8	
111	S	(3.68 ± 0.04)x10-6	1.02 x 10-5	.361 ± .101
112			9.40 x 10-5	

Table B1 . (Con't.)

Relay No.	Flow	Q_s^R(atm. cc/sec) (RAG)	Q_s^{MS}(atm.cc/sec) (HMS)	$R=Q_s^R/Q_s^{MS} \pm \sigma$
114				
115	P	(7.73 ± 0.08)x10-7	9.50 x 10-6	.081 $\pm$ .101
116	P	(1.13 ± 0.01)x10-6	1.36 x 10-5	.083 $\pm$ .100
117				
118	S	(1.39 ± 0.03)x10-6	8.00 x 10-6	.174 $\pm$ .103
119			Gross	
120	M	(7.00 ± 1.07)x10-8	6.20 x 10-7	.113 $\pm$ .182
121			2.75 x 10-7	
122			4.40 x 10-7	
123	P	(8.96 ± 0.08)x10-7	7.80 x 10-6	.115 $\pm$ .100
124	S	(1.97 ± 0.03)x10-6	1.30 x 10-5	.152 $\pm$ .102
125	M	(2.79 ± 0.21)x10-7	1.90 x 10-6	.147 $\pm$ .126
126			6.00 x 10-5	
127			6.20 x 10-6	
128			1.00 x 10-5	
129	M	(2.62 ± 0.11)x10-7	9.00 x 10-7	.291 $\pm$ .108
130	M	(5.00 ± 0.21)x10-7	2.40 x 10-6	.208 $\pm$ .109
131	S	(7.23 ± 0.34)x10-7	8.60 x 10-6	.084 $\pm$ .110
132	M	(2.11 ± 0.02)x10-6	4.50 x 10-6	.468 $\pm$ .101
133	M	(4.32 ± 0.03)x10-6	1.16 x 10-5	.372 $\pm$ .100
134	S	(1.78 ± 0.22)x10-7	1.20 x 10-6	.149 $\pm$ .158
135	S	(1.26 ± 0.27)x10-8	1.80 x 10-7	.070 $\pm$ .236
138			3.60 x 10-5	
139				
140	M	(7.91 ± 0.14)x10-7	3.60 x 10-6	.220 $\pm$ .102
141	M	(1.90 ± 0.11)x10-7	6.60 x 10-7	.287 $\pm$ .115
142	M	(2.64 ± 0.11)x10-7	1.00 x 10-6	.264 $\pm$ .108
143	S	(4.72 ± 0.34)x10-7	5.10 x 10-6	.093 $\pm$ .123
144			2.00 x 10-5	
145	M	(2.10 ± 0.04)x10-6	5.80 x 10-6	.361 $\pm$ .102
146			7.80 x 10-8	
147			4.05 x 10-7	
148	P	(1.46 ± 0.01)x10-6	1.30 x 10-5	.112 $\pm$ .100
149	M	(2.23 ± 0.21)x10-7	2.00 x 10-6	.112 $\pm$ .138
150			1.50 x 10-5	
152			2.70 x 10-8	
154			4.45 x 10-8	
155			1.20 x 10-9	
156			1.38 x 10-7	
157			3.65 x 10-7	
158	S	(5.06 ± 0.22)x10-7	2.65 x 10-6	.191 $\pm$ .109
159			5.80 x 10-8	
162	M	(6.71 ± 0.30)x10-8	1.08 x 10-7	.621 $\pm$ .110
163			0.00	
164			2.30 x 10-7	
165			2.00 x 10-9	
166	S	(3.03 ± 0.11)x10-7	7.00 x 10-7	.433 $\pm$ .106

Table B1 . (Con't.)

Relay No.	Flow	Q_s^R(atm.cc/sec.) (RAG)	Q_s^{MS}(atm.cc/sec) (HMS)	$R=Q_s^R/Q_s^{MS} \pm \sigma$
167			6.00 x 10-8	
170	S	(4.73 ± 0.22)x10-7	2.80 x 10-6	.169 ± .110
172			1.61 x 10-8	
173			1.70 x 10-9	
174			6.50 x 10-8	
175			4.70 x 10-7	
177			3.00 x 10-7	
178	M	(1.59 ± 0.04)x10-6	5.20 x 10-6	.306 ± .103
181	S	(3.81 ± 0.22)x10-7	2.50 x 10-6	.177 ± .115
182			4.00 x 10-9	
183	S	(1.93 ± 0.11)x10-7	8.20 x 10-7	.235 ± .115
184	S	(3.09 ± 0.11)x10-7	6.20 x 10-7	.498 ± .106
185			3.80 x 10-7	
186			7.00 x 10-9	
187A	S	(3.37 ± 0.13)x10-7	7.50 x 10-7	.449 ± .107
187B	M	(1.71 ± 0.03)x10-7	1.95 x 10-7	.878 + .101
188			6.00 x 10-6	
189	S	(2.11 ± 0.11)x10-7	7.00 x 10-7	1.05 ± .113
191			3.20 x 10-8	
192			3.10 x 10-7	
195			5.00 x 10-8	
196	M	(3.55 ± 0.21)x10-7	1.16 x 10-6	.306 ± .117
197			7.15 x 10-8	
198			5.00 x 10-9	
199	P	(2.54 ± 0.26)x10-8	8.10 x 10-7	.031 ± .142
200			5.00 x 10-7	
201			3.50 x 10-8	
202	M	(1.77 ± 0.30)x10-7	1.40 x 10-6	.126 ± .197
203			1.00 x 10-7	
204	M	(6.82 ± 0.28)x10-8	1.60 x 10-7	.426 ± .108
205			3.20 x 10-8	
207	S	(2.13 ± 0.11)x10-7	7.20 x 10-7	.296 ± .112
208	M	(6.98 ± 0.21)x10-7	1.85 x 10-6	.377 ± .105
209	S	(1.46 ± 0.03)x10-6	5.20 x 10-6	.281 ± .103
210			2.15 x 10-6	
211			8.00 x 10-8	
214			2.90 x 10-6	
215	S	(6.65 ± 1.09)x10-8	8.00 x 10-7	.083 ± .192
216			3.30 x 10-7	
217			2.96 x 10-7	
218			4.50 x 10-7	
221	S	(2.12 ± 0.11)x10-7	7.00 x 10-7	.303 ± .112
222			2.50 x 10-6	
223	S	(1.00 ± 0.03)x10-6	5.20 x 10-6	.193 ± .106
224	S	(4.13 ± 0.34)x10-7	4.60 x 10-6	.090 ± .129
225			3.40 x 10-7	
226	M	(4.62 ± 0.21)x10-7	1.38 x 10-6	.335 ± .110

Table B1 . (Con't.)

Relay No.	Flow	Q_S^R(Atm.cc/sec) (RAG)	Q_s^{MS}(atm.cc/sec) (HMS)	$R=Q_S^R/Q_S^{MS} \pm \sigma$
227			3.05 x 10-8	
228			8.00 x 10-8	
229	M	(8.99 ± 0.46)x10-8	2.70 x 10-7	.333 ± .112
230			4.20 x 10-7	
231	M	(7.24 ± 0.46)x10-8	2.40 x 10-7	
232			4.00 x 10-9	
233			2.80 x 10-7	
234			3.60 x 10-8	
235	M	(6.32 ± 0.21)x10-7	1.56 x 10-6	.405 ± .106
236	M	(3.28 ± 0.05)x10-7	2.45 x 10-7	1.340 ± .101
237			6.10 x 10-7	
238	S	(8.76 ± 1.09)x10-8	6.80 x 10-7	.129 ± .159
239			4.40 x 10-7	
241	S	(2.15 ± 0.22)x10-7	1.14 x 10-6	.188 ± .142
243			6.70 x 10-8	
244	M	(1.15 ± 0.05)x10-7	2.50 x 10-7	.461 ± .108
245			5.50 x 10-8	
247			1.20 x 10-8	
248			1.20 x 10-7	
249			6.00 x 10-8	
250			0.00	
251			1.18 x 10-7	
252	S	(3.16 ± 0.35)x10-8	1.08 x 10-7	.293 ± .149
253			1.60 x 10-9	
255			0.00	
256	M	(2.18 ± 0.11)x10-7	6.80 x 10-7	.320 ± .111
257			1.50 x 10-8	
258	M	(7.69 ± 0.26)x10-8	1.80 x 10-7	.427 ± .106
259			0.00	
260	M	(1.86 ± 0.11)x10-7	6.30 x 10-7	.295 ± .115
261			5.20 x 10-8	
262	M	(4.66 ± 0.28)x10-8	2.02 x 10-7	.231 ± .117
263			0.00	
264	M	(5.01 ± 0.26)x10-8	1.30 x 10-7	.386 ± .113
265			0.00	
266	M	(3.01 ± 0.21)x10-7	1.00 x 10-6	.301 ± .123
267	M	(3.87 ± 0.34)x10-8	1.75 x 10-7	.221 ± .134
268	M	(4.55 ± 0.29)x10-8	1.28 x 10-7	.355 ± .119
269	M	(1.36 ± 0.05)x10-7	2.22 x 10-7	.610 ± .106
270			4.50 x 10-8	
271			4.90 x 10-7	
272			0.00	
273			3.30 x 10-7	
274	M	(5.60 ± 0.26)x10-8	1.45 x 10-7	.386 ± .111
275	M	(7.50 ± 0.26)x10-8	1.98 x 10-7	.379 ± .106
276	M	(1.03 ± 0.05)x10-7	2.70 x 10-7	.380 ± .110
277	S	(3.42 ± 0.14)x10-7	6.60 x 10-7	.518 ± .108

Table B1. (Con't.)

Relay No.	Flow	Q_s^R(Atm.cc/sec) (RAG)	Q_s^{MS} (atm.cc/sec) (HMS)	$R=Q_s^R/Q_s^{MS} \pm \sigma$
278			3.50 x 10-7	
279			1.44 x 10-8	
280			0.00	
281			5.00 x 10-7	
282	M	(2.62 ± 0.12)x10-7	1.45 x 10-6	.180 ± .109
283			5.20 x 10-8	
284			3.10 x 10-8	
285			2.75 x 10-6	
286			6.00 x 10-8	
287			1.80 x 10-8	
288			6.40 x 10-8	
289			0.00	
290	M	(7.37 ± 1.23)x10-8	6.50 x 10-7	.113 ± .195
291			3.00 x 10-7	
294			4.30 x 10-8	
295	M	(1.63 ± 0.34)x10-8	1.25 x 10-7	.130 ± .233

LEGEND; P = Poiseuille
S = Slip
M = Molecular

10 - 7 = 10^{-7} (etc.)

Table B2. RAG and HMS Leak Rates for Half-Size Relays

Relay No.	Flow	Q_S^R(atm.cc/sec) (RAG)	Q_S^{MS} (atm.cc/sec) (HMS)	$R=Q_S^R/Q_S^{MS} \pm \sigma$
1	S	(2.59 ± 0.42)x10-7	7.64 x 10-7	.339 ± .189
3	M	(7.54 ± 3.86)x10-9	5.00 x 10-8	.151 ± .522
4			1.43 x 10-9	
5	S	(1.42 ± 1.58)x10-8	2.09 x 10-7	.068 ± 1.12
6	M	(6.23 ± 0.18)x10-7	1.51 x 10-6	.413 ± .104
7	M	(7.60 ± 2.01)x10-8	2.24 x 10-7	.339 ± .283
8	S	(7.48 ± 0.42)x10-7	3.10 x 10-6	.241 ± .114
9	S	(1.09 ± 0.16)x10-7	1.16 x 10-6	.094 ± .176
12			9.00 x 10-6	
13	M	(3.85 ± 0.49)x10-7	4.74 x 10-6	.812 ± .159
14			3.20 x 10-7	
15	S	(7.98 ± 1.58)x10-8	7.50 x 10-7	.106 ± .221
16			5.82 x 10-9	
18	M	(1.82 ± 0.04)x10-6	6.00 - 10-6	.303 ± .102
19			2.04 x 10-7	
20	S	(9.89 ± 0.42)x10-7	4.14 x 10-6	.239 ± .109
21	P	(6.37 ± 0.93)x10-8	6.10 x 10-6	.010 ± .177
22			5.82 x 10-9	
23			2.91 x 10-9	
24	S	(7.33 ± 0.45)x10-7	4.50 x 10-6	.163 ± .118
26			3.35 x 10-7	
27			1.10 x 10-6	
29			6.00 x 10-7	
30	P	(7.63 ± 1.55)x10-9	1.13 x 10-7	.068 ± .227
31			1.05 x 10-7	
32	M	(5.26 ± 0.15)x10-7	1.48 x 10-6	.355 ± .104
33			1.63 x 10-8	
34	S	(2.03 ± 0.16)x10-7	6.12 x 10-7	.332 ± .127
35	M	(1.04 ± 0.15)x10-7	2.78 x 10-7	.373 ± .179
36	P	(4.44 ± 0.31)x10-8	3.40 x 10-7	.131 ± .122
37	S	(3.94 ± 0.83)x10-8	1.28 x 10-7	.308 ± .232
38	M	(4.88 ± 0.15)x10-7	6.55 x 10-7	.745 ± .105
40	M	(1.58 ± 0.15)x10-7	5.50 x 10-7	.287 ± .140
41			1.68 x 10-7	
42	P	(1.42 ± 0.37)x10-8	4.00 x 10-7	.035 ± .280
43			2.14 x 10-6	
44			1.15 x 10-7	
45	M	(1.26 ± 0.15)x10-7	3.42 x 10-7	.369 ± .158
46			4.95 x 10-8	
49	P	(3.01 ± 1.55)x10-9	1.16 x 10-7	.026 ± .526
50	S	(2.57 ± 0.03)x10-8	2.04 x 10-7	.126 ± .337
51	S	(9.14 ± 0.42)x10-7	3.00 x 10-6	.305 ± .110
52			2.04 x 10-7	
53	S	(1.29 ± 0.04)x10-6	3.00 x 10-6	.429 ± .105
56	S	(1.27 ± 0.08)x10-7	1.79 x 10-7	.985 ± .119

Table B2. (Con't.)

Relay No.	Flow	Q_s^R(atm.cc/sec) (RAG)	Q_s^{MS}(atm.cc/sec) (HMS)	$R=Q_s^R/Q_s^{MS} \pm \sigma$
58				
59	S	(9.77 ± 1.82)x10-8	2.85 x 10-7	.343 ± .212
60			2.40 x 10-8	
61	M	(2.48 ± 0.18)x10-7	1.68 x 10-7	.148 ± .123
62			3.40 x 10-7	
64	M	(5.47 ± 3.86)x10-9	4.00 x 10-8	.137 ± .713
66			2.11 x 10-9	
67	S	(9.83 ± 1.94)x10-8	4.00 x 10-7	.246 ± .221
68			1.96 x 10-5	
69			7.50 x 10-6	
71			1.00 x 10-9	
73			9.25 x 10-9	
74			7.97 x 10-8	
75			1.38 x 10-8	
76			4.17 x 10-8	
77			2.80 x 10-8	
78			3.05 x 10-9	
79			2.09 x 10-8	
80			1.00 x 10-9	
81			2.80 x 10-7	
82	M	(1.11 ± 0.39)x10-8	5.10 x 10-8	.217 ± .363
83	S	(6.81 ± 0.16)x10-7	1.75 x 10-6	.389 ± .103
84			4.65 x 10-9	
85	S	(1.53 ± 0.16)x10-7	4.70 x 10-7	.324 ± .144
87			2.20 x 10-9	
88			1.16 x 10-8	
89			1.85 x 10-9	
90			5.80 x 10-9	
92			3.10 x 10-9	
93	P	(1.33 ± 0.16)x10-8	1.40 x 10-7	.095 ± .154
95			1.85 x 10-8	
96	M	(1.83 ± 0.18)x10-7	2.78 x 10-7	.659 ± .140
97			4.42 x 10-8	
98	P	(1.25 ± 0.16)x10-8	2.00 x 10-7	.063 ± .159
101	P	(6.54 ± 0.93)x10-9	5.15 x 10-8	.127 ± .173
102			5.34 x 10-9	
103	M	(5.66 ± 3.86)x10-9	4.99 x 10-8	.113 ± .690
104	M	(3.63 ± 0.11)x10-8	9.00 x 10-8	.403 ± .317
107			1.28 x 10-8	
108			2.09 x 10-8	
109			6.62 x 10-7	
110			2.24 x 10-8	
112			3.50 x 10-9	
113	M	(5.10 ± 7.72)x10-9	1.25 x 10-7	.041 ± 1.51
114	S	(2.48 ± 3.94)x10-9	4.10 x 10-8	.060 ± 1.59
115			4.60 x 10-9	
116	S	(1.63 ± 5.13)x10-9	4.41 x 10-8	.037 ± 3.14

Table B2 . (Con't.)

Relay No.	Flow	Q_s^R(atm.cc/sec) (RAG)	Q_s^{MS}(Atm.cc/sec) (HMS)	$R=Q_s^R/Q_s^{MS} \pm \sigma$
117	S	(8.77 ± 1.58)x10-8	2.32 x 10-7	.378 ± .206
118			1.40 x 10-8	
119			9.30 x 10-9	
120	S	(1.93 ± 7.87)x10-9	9.30 x 10-8	.021 ± 4.08
121			1.60 x 10-8	
123			2.55 x 10-8	
124			4.20 x 10-8	
125			2.90 x 10-8	
126	M	(2.92 ± 0.39)x10-8	7.43 x 10-8	.393 ± .166
127	M	(1.25 ± 0.50)x10-8	6.73 x 10-8	.086 ± .414
128			9.28 x 10-8	
130			8.13 x 10-8	
131	M	(1.93 ± 0.81)x10-8	9.05 x 10-8	.213 ± .431
132			5.00 x 10-9	
133			4.64 x 10-8	
134	S	(1.47 ± 0.83)x10-8	1.04 x 10-7	.142 ± .570
135	P	(8.07 ± 1.55)x10-9	1.05 x 10-7	.077 ± .217
136	M	(3.06 ± 0.95)x10-8	1.16 x 10-7	.263 ± .327
137			1.40 x 10-8	
138	M	(2.59 ± 0.81)x10-8	1.16 x 10-7	.223 ± .329
141			2.60 x 10-8	
142	M	(5.28 ± 3.86)x10-9	4.20 x 10-8	.126 ± .738
143			4.30 x 10-8	
144			5.80 x 10-9	
145			8.50 x 10-8	
146			2.10 x 10-7	
147	P	(9.92 ± 1.55)x10-9	1.14 x 10-7	.087 ± .186
149			2.32 x 10-9	
150			2.90 x 10-8	
151	S	(3.00 ± 0.79)x10-8	1.90 x 10-7	.158 ± .281
152			7.00 x 10-8	
154	S	(8.21 ± 1.58)x10-8	2.14 x 10-7	.384 ± .216
157	M	(2.98 ± 0.39) x10-8	9.30 x 10-8	.320 ± .164
158			1.16 x 10-8	
159			4.90 x 10-8	
160			5.60 x 10-8	
161			7.00 x 10-6	
162			1.70 x 10-6	
163	P	(8.68 ± 1.55)x10-9	1.65 x 10-7	.053 ± .205
164	M	(5.82 ± 0.41)x10-7	3.00 x 10-6	.194 ± .122
165			6.96 x 10-9	
166			3.50 x 10-9	
169	M	(1.79 ± 0.18)x10-7	3.71 x 10-7	.484 ± .141
170	M	(8.91 ± 3.86)x10-9	7.66 x 10-8	.116 ± .445
171			3.48 x 10-8	
175			3.70 x 10-5	
176			3.89 x 10-6	

Table B2 . (Con't.)

Relay No.	Flow	Q_s^R(atm.cc/sec) (RAG)	Q_s^{MS}(Atm.cc/sec) (HMS)	$R=Q_s^R/Q_s^{MS} \pm \sigma$
177	S	(5.70 ± 0.04)x10-7	8.12 x 10-8	7.02 ± .100
178			2.55 x 10-8	
179			3.95 x 10-8	
182	M	(1.30 ± 0.18)x10-7	4.06 x 10-7	.320 ± .170
183			2.60 x 10-5	
184			6.50 x 10-8	
186	S	(9.13 ± 0.22)x10-7	1.42 x 10-6	.643 ± .103
187			5.80 x 10-9	
188	M	(1.44 ± 0.04)x10-6	2.90 x 10-6	.497 ± .104
189			1.16 x 10-8	
190			2.32 x 10-9	
192			2.10 x 10-8	
193			1.87 x 10-6	
194	S	(2.80 ± 7.87)x10-9	1.70 x 10-7	.016 ± 2.82
195			9.00 x 10-5	
196				
197			2.32 x 10-9	
198			1.39 x 10-8	
200				
201				
202			7.40 x 10-6	
203			1.62 x 10-8	
204	S	(1.76 ± 0.16)x10-7	3.25 x 10-7	.541 ± .134
205			3.48 x 10-8	
206			3.25 x 10-9	
207			3.94 x 10-8	
208			9.30 x 10-9	
209			1.20 x 10-5	
210	S	(4.18 ± 0.22)x10-7	1.86 x 10-6	.225 ± .113
211			5.80 x 10-9	
214			5.00 x 10-9	
215	P	(1.16 ± 0.05)x10-7	1.70 x 10-6	.068 ± .109
216			2.50 x 10-10	
217			1.70 x 10-8	
219			4.51 x 10-6	
221			9.80 x 10-5	
222	M	(1.48 ± 0.50)x10-8	5.05 x 10-8	.294 ± .353
223			6.00 x 10-9	
224				
227			1.02 x 10-5	
232			3.50 x 10-7	
233			2.88 x 10-8	
234			9.40 x 10-5	
235	M	(2.38 ± 0.15)x10-7	6.00 x 10-7	.396 ± .119
237			2.40 x 10-5	
240			1.32 x 10-6	
241	S	(2.15 ± 0.17)x10-7	7.00 x 10-7	.307 ± .128
242			1.95 x 10-6	

Table B2 (Con't.)

Relay No.	Flow	Q_S^R(atm.cc/sec) (RAG)	Q_S^{MS}(Atm.cc/sec) (HMS)	$R=Q_S^R/Q_S^{MS} \pm \sigma$
243	S	(4.06 ± 0.16)x10-7	1.19 x 10-6	.341 ± .107
246			1.90 x 10-6	
247			2.26 x 10-5	
248			5.50 x 10-9	
249			5.40 x 10-5	
250			6.00 x 10-10	
252			1.75 x 10-9	
254			2.20 x 10-5	
260				
261				
263				
266				
270				
271	S	(7.83 ± 0.49)x10-7	1.00 x 10-6	.783 ± .118
272			1.20 x 10-5	
273	S	(8.60 ± 1.58)x10-8	2.10 x 10-7	.410 ± .209
274	M	(2.61 ± 0.39)x10-8	6.00 x 10-8	.429 ± .179
276	M	(1.94 ± 0.04)x10-6	5.90 x 10-6	
277			1.00 x 10-5	.329 ± .102
278	M	(1.57 ± 0.04)x10-6	6.10 x 10-6	
279			1.10 x 10-8	.257 ± .103
280			1.90 x 10-8	
281			3.80 x 10-7	
283	S	(4.48 ± 0.42)x10-7	1.80 x 10-6	.249 ± .137
284	M	(2.95 ± 0.41)x10-7	1.30 x 10-6	.227 ± .170
285	M	(5.08 ± 0.41)x10-7	3.00 x 10-6	.170 ± .128
286	S	(6.67 ± 0.42)x10-7	2.96 x 10-6	.225 ± .118
287	M	(1.27 ± 0.04)x10-6	4.74 x 10-6	.269 ± .105
288			8.00 x 10-8	
289			6.50 x 10-9	
290		(2.45 ± 0.41)x10-7	1.70 x 10-6	.204 ± .193
291	M		1.20 x 10-6	
292			2.45 x 10-7	
293	M	(7.70 ± 2.01)x10-8	8.00 x 10-7	.096 ± .270
294				
295	M	(1.47 ± 0.18)x10-7	2.15 x 10-7	.683 ± .157
296	M	(2.52 ± 0.41)x10-7	1.10 x 10-6	.230 ± .190
297			3.70 x 10-6	
298			3.20 x 10-7	
299	S	(6.30 ± 0.42)x10-7	2.40 x 10-6	.263 ± .120
300	M	(2.11 ± 0.18)x10-7	4.10 x 10-7	.516 ± .131
301			2.00 x 10-9	
302			8.20 x 10-6	
305			1.20 x 10-5	
306	M	(1.62 ± 0.41)x10-7	1.60 x 10-6	.101 ± .269
307			1.40 x 10-8	
308	S	(1.24 ± 0.04)x10-6	3.60 x 10-6	.346 ± .105
310	M	(1.51 ± 0.04)x10-6	4.60 x 10-6	.329 ± .104

Table B2 . (Con't.)

Relay No.	Flow	Q_s^R(atm.cc/sec) (RAG)	Q_S^M(Atm.cc/sec) (HMS)	$R=Q_s^R/Q_s^{MS} \pm \sigma$
311			2.80 x 10-6	
313			6.00 x 10-9	
314	S	(1.35 ± 0.42)x10-7	1.00 x 10-6	.135 ± .324
316			3.20 x 10-6	
317			1.00 x 10-5	
318			8.00 x 10-9	
319	M	(1.79 ± 0.18)x10-7	4.10 x 10-7	.431 ± .141

Legend: P = Poiseuille
S = Slip
M = Molecular

10 - 7 = 10^{-7} (etc.,)

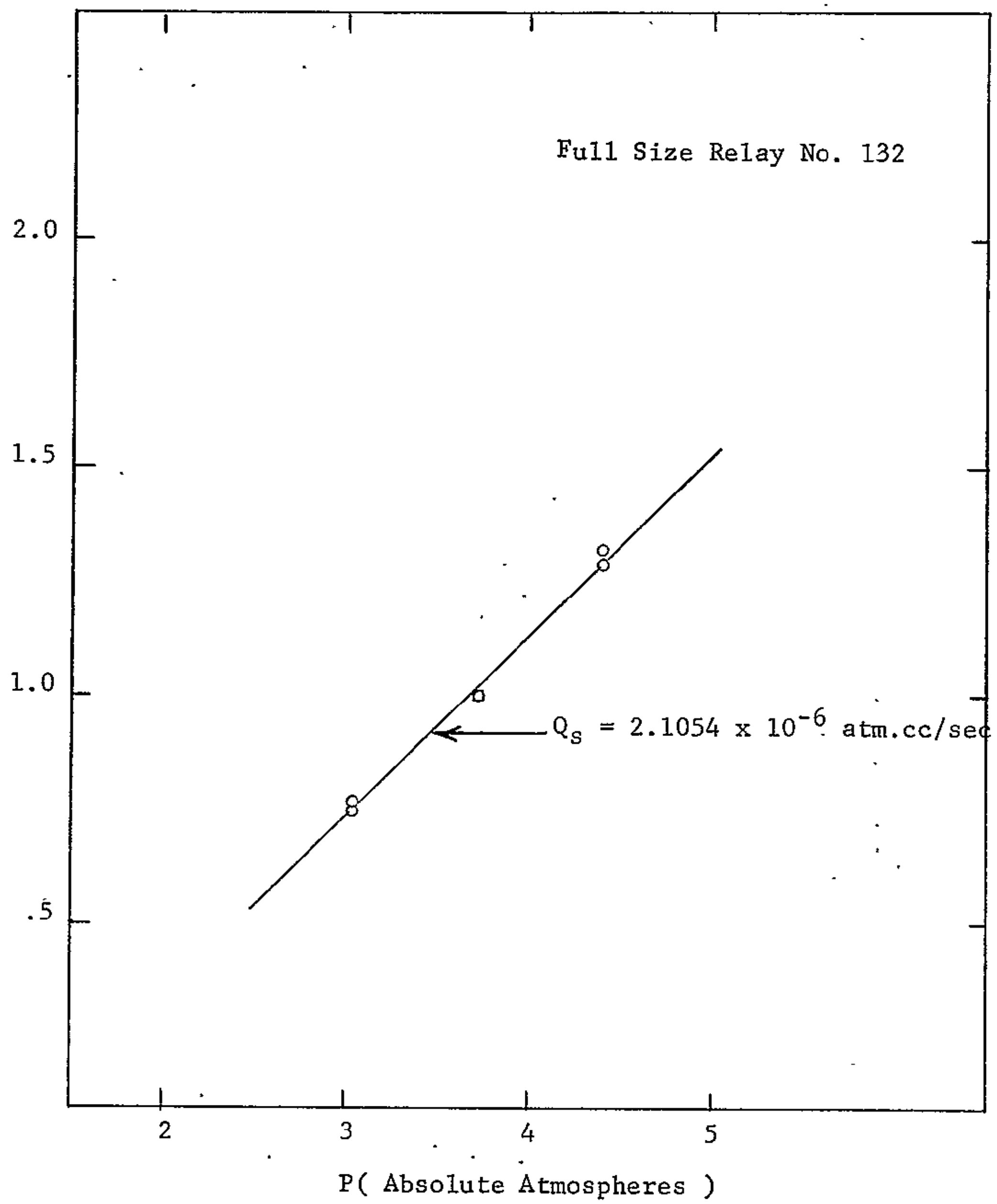

Fig.B1 Example of Relay Exhibiting Molecular Flow

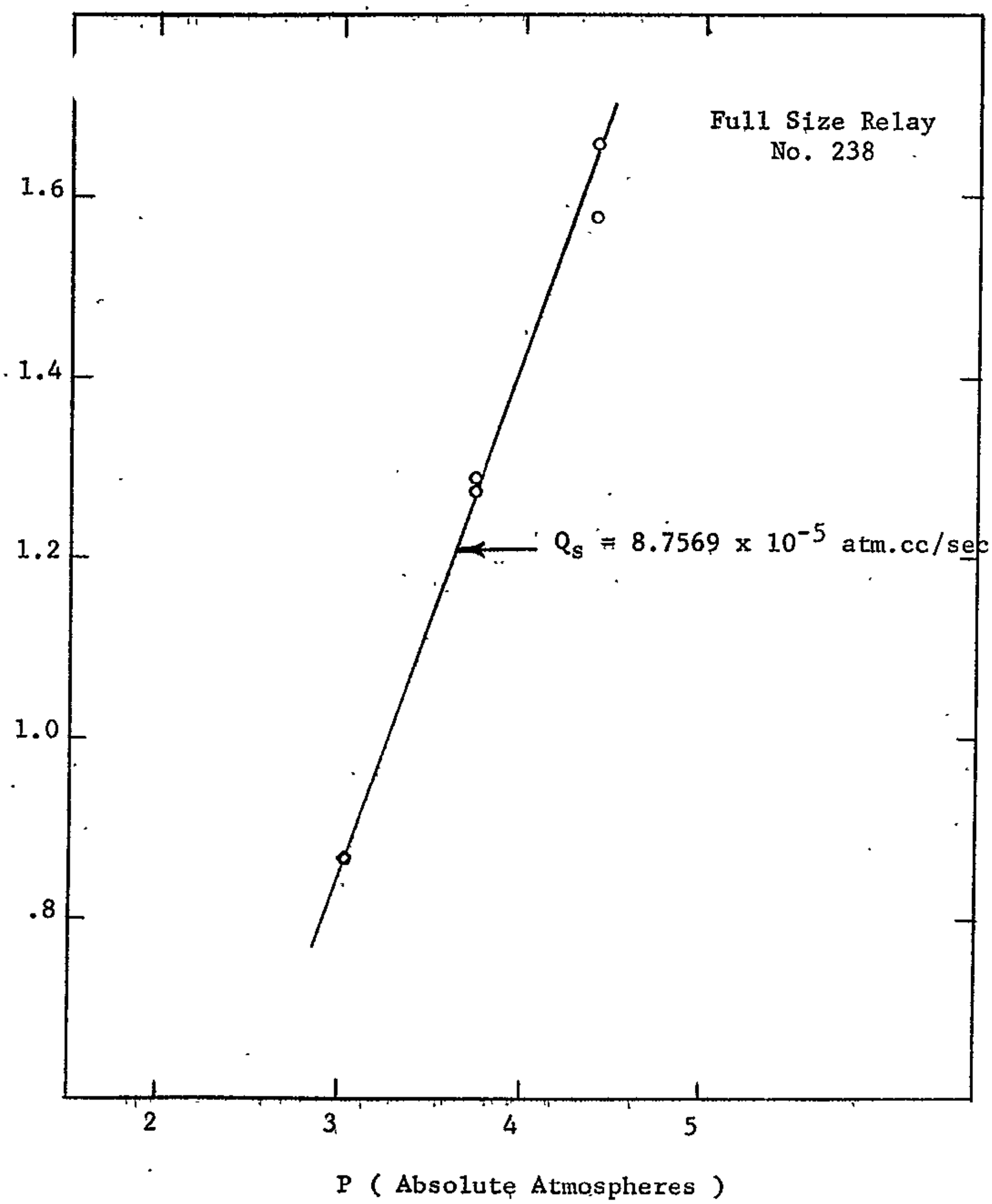

Fig.B2. Example of Relay Exhibiting Slip Flow

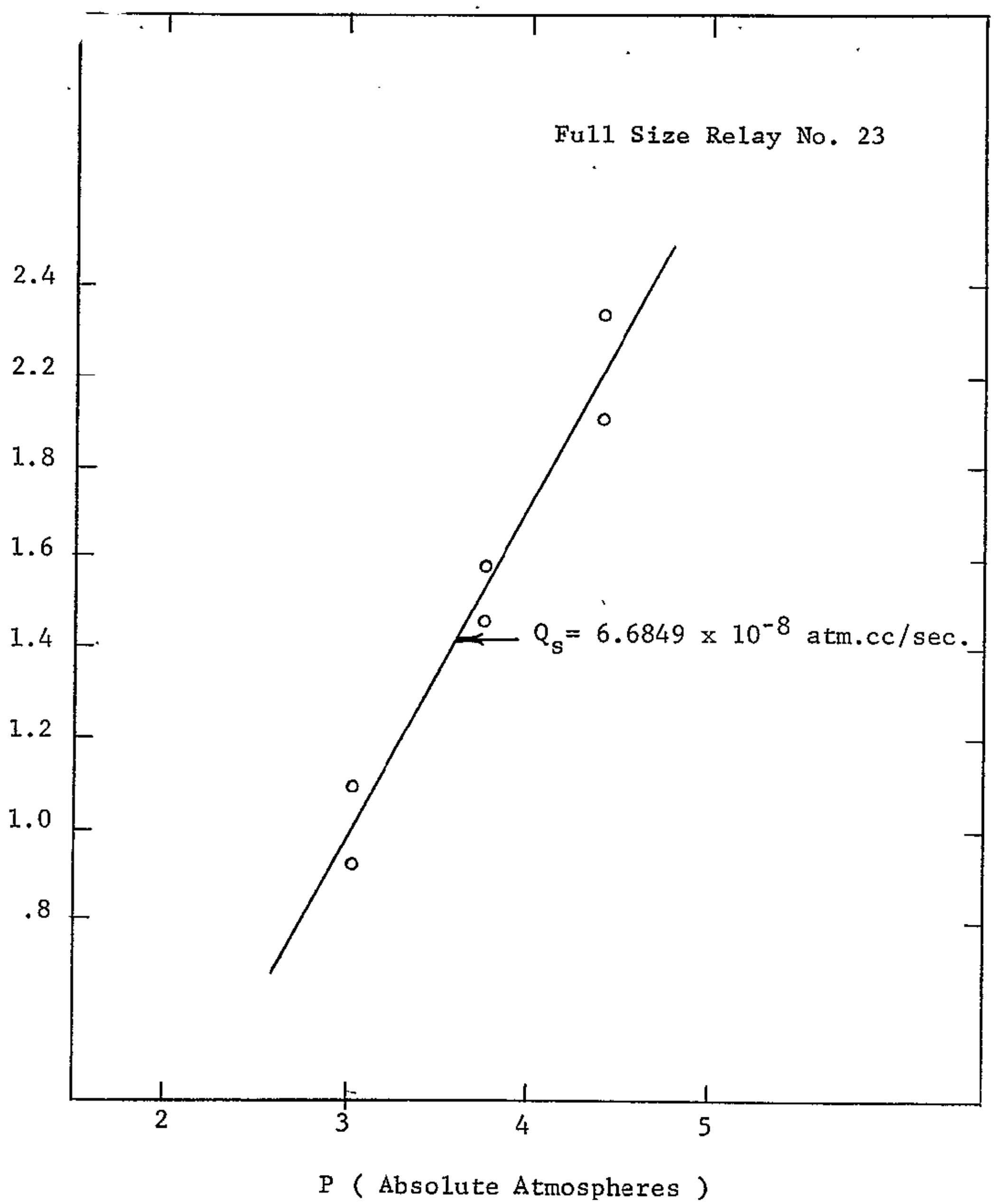

Fig.B3. Example of Relay Exhibiting Poiseuille Flow

APPENDIX C

FORM 1027-11-64 5M

Mississippi State Chemical Laboratory

State College, Mississippi

M. P. ETHEREDGE
STATE CHEMIST

Analysis No. 381,808-809

Analysis of CONTACT WIRES Marked:

Received on 6/2/67 from Dr. J. I. Paulk
Nuclear Engineering Dept.

Address State College, Mississippi Drawer NE

RESULTS:

Dear Professor Paulk:

Bill Patterson finds that the wires definitely contain iron and nickel. Apparently, these are plated with gold.

Sincerely yours,

State Chemist

PLEASE GIVE NUMBER WHEN REFERING TO THIS ANALYSIS

APPENDIX D

RAG-HMS CORRELATION

Table D1. RAG-HMS Correlation Using Experimentally Determined Correlation Factors, Full Size Relays

Relay No.	Flow	Q_S^R(atm cc/sec)	Q_s^{MS} x $\overline{R}$ (atm. cc/sec)
1	M	8.36 x 10-7	11.90 x 10-7
2	M	3.60 x 10-8	2.44 x 10-8
7	M	2.39 x 10-7	2.66 x 10-7
11	M	4.45 x 10-8	6.45 x 10-8
14	M	4.21 x 10-8	4.06 x 10-8
15	M	9.60 x 10-8	2.88 x 10-7
32	M	1.12 x 10-8	2.03 x 10-7
38	M	6.95 x 10-7	1.25 x 10-6
43	M	1.97 x 10-6	2.19 x 10-6
46	M	5.50 x 10-7	7.21 x 10-7
48	M	1.42 x 10-8	5.23 x 10-8
69	M	3.06 x 10-6	2.07 x 10-6
70	M	5.80 x 10-8	4.38 x 10-8
76	M	5.69 x 10-7	5.38 x 10-7
89	M	4.21 x 10-7	1.38 x 10-6
90	M	2.80 x 10-7	9.39 x 10-7
91	M	6.98 x 10-8	8.45 x 10-8
102	M	9.47 x 10-8	7.82 x 10-8
103	M	1.18 x 10-7	3.44 x 10-7
105	M	1.66 x 10-7	2.51 x 10-7
108	M	3.60 x 10-7	1.065 x 10-6
120	M	7.00 x 10-8	1.94 x 10-7
125	M	2.79 x 10-7	5.95 x 10-7
129	M	2.62 x 10-7	2.72 x 10-7
130	M	5.00 x 10-7	7.52 x 10-7
132	M	2.11 x 10-6	1.41 x 10-6
133	M	4.32 x 10-6	3.63 x 10-6
140	M	7.91 x 10-7	1.13 x 10-6
141	M	1.90 x 10-7	2.07 x 10-7
142	M	2.64 x 10-7	3.13 x 10-7
145	M	2.10 x 10-6	1.82 x 10-6
149	M	2.23 x 10-7	6.26 x 10-7
162	M	6.71 x 10-8	3.38 x 10-8
178	M	1.59 x 10-6	1.63 x 10-6
187B	M	1.71 x 10-7	6.10 x 10-8
196	M	3.55 x 10-7	3.63 x 10-7
202	M	1.77 x 10-7	4.38 x 10-7
204	M	6.82 x 10-8	5.00 x 10-8
208	M	6.98 x 10-7	5.79 x 10-7
226	M	4.62 x 10-7	4.31 x 10-7
229	M	8.99 x 10-8	8.44 x 10-8
231	M	7.24 x 10-8	7.50 x 10-8
235	M	6.32 x 10-7	4.88 x 10-7
236	M	3.28 x 10-7	7.66 x 10-8
244	M	1.15 x 10-7	7.82 x 10-8
256	M	2.18 x 10-7	2.13 x 10-7
258	M	7.69 x 10-8	5.64 x 10-8
260	M	1.86 x 10-7	1.98 x 10-7
262	M	4.66 x 10-8	6.32 x 10-8

Table D1. (Con't.)

Relay No.	Flow	Q_S^R (atm cc/sec)	$Q_S^{MS} \times \bar{R}$ (atm. cc/sec)
264	M	5.01 x 10-8	4.07 x 10-8
266	M	3.01 x 10-7	3.13 x 10-7
267	M	3.87 x 10-8	5.48 x 10-8
268	M	4.55 x 10-8	4.00 x 10-8
269	M	1.36 x 10-7	6.95 x 10-8
274	M	5.60 x 10-8	4.54 x 10-8
275	M	7.50 x 10-8	6.20 x 10-8
276	M	1.03 x 10-7	8.45 x 10-8
282	M	2.62 x 10-7	4.54 x 10-7
290	M	7.37 x 10-8	2.03 x 10-7
295	M	1.63 x 10-8	3.92 x 10-8
20	S	8.90 x 10-7	1.31 x 10-6
27	S	9.38 x 10-7	2.48 x 10-6
37	S	3.03 x 10-7	4.75 x 10-7
63	S	1.63 x 10-6	2.95 x 10-6
64	S	2.29 x 10-8	2.57 x 10-7
74	S	8.59 x 10-7	1.28 x 10-6
82	S	1.67 x 10-6	2.57 x 10-6
94	S	1.57 x 10-7	2.36 x 10-7
111	S	3.68 x 10-6	2.39 x 10-6
118	S	1.39 x 10-6	1.87 x 10-6
124	S	1.97 x 10-6	3.04 x 10-6
131	S	7.23 x 10-7	2.01 x 10-6
134	S	1.78 x 10-7	2.81 x 10-7
135	S	1.26 x 10-8	4.21 x 10-8
143	S	4.72 x 10-7	1.19 x 10-7
158	S	5.06 x 10-7	6.20 x 10-7
166	S	3.03 x 10-7	1.64 x 10-7
170	S	4.73 x 10-7	6.55 x 10-7
181	S	3.81 x 10-7	5.85 x 10-7
183	S	1.93 x 10-7	1.92 x 10-7
184	S	3.09 x 10-7	1.45 x 10-7
187A	S	3.37 x 10-7	1.76 x 10-7
189	S	2.11 x 10-7	1.64 x 10-7
207	S	2.13 x 10-7	1.68 x 10-7
209	S	1.46 x 10-6	1.22 x 10-6
215	S	6.65 x 10-8	1.87 x 10-7
221	S	2.12 x 10-7	1.64 x 10-7
223	S	1.00 x 10-6	1.22 x 10-6
224	S	4.13 x 10-7	1.08 x 10-6
238	S	8.76 x 10-8	1.57 x 10-7
241	S	2.15 x 10-7	2.67 x 10-7
252	S	3.16 x 10-8	2.53 x 10-8
277	S	3.42 x 10-7	1.55 x 10-7
21	P	8.19 x 10-7	7.85 x 10-7
23	P	6.69 x 10-8	9.60 x 10-8
47	P	1.05 x 10-6	1.28 x 10-6

Table D1 Con't.

Relay No.	Flow	Q_S^R (atm cc/sec)	$Q_s^{MS} \times \overline{R}$ (atm. cc/sec)
56	P	1.15 x 10-6	1.04 x 10-6
62	P	3.46 x 10-8	7.85 x 10-8
71	P	1.16 x 10-6	9.60 x 10-7
115	P	7.73 x 10-7	7.60 x 10-7
116	P	1.13 x 10-6	1.09 x 10-6
123	P	8.96 x 10-7	6.24 x 10-7
148	P	1.46 x 10-6	1.04 x 10-6

Table D2. RAG-HMS Correlation Using Experimentally Determined Correlation Factors, Half Size Relays

Relay No.	Flow	Q_S^R (atm. cc/sec)	$Q_s^{MS} \times \bar{R}$ (atm. cc/sec)
3	M	7.54×10^{-9}	1.64×10^{-8}
6	M	6.23×10^{-7}	4.96×10^{-7}
7	M	7.60×10^{-8}	7.35×10^{-8}
13	M	3.85×10^{-7}	1.55×10^{-6}
18	M	1.82×10^{-6}	1.97×10^{-6}
32	M	5.26×10^{-7}	4.78×10^{-7}
35	M	1.04×10^{-7}	8.99×10^{-8}
38	M	4.88×10^{-7}	2.15×10^{-7}
40	M	1.58×10^{-7}	1.80×10^{-7}
45	M	1.26×10^{-7}	1.12×10^{-7}
61	M	2.48×10^{-7}	5.51×10^{-8}
64	M	5.47×10^{-9}	1.31×10^{-8}
82	M	1.11×10^{-8}	1.67×10^{-8}
96	M	1.83×10^{-7}	9.10×10^{-8}
103	M	5.66×10^{-9}	1.64×10^{-8}
104	M	3.63×10^{-8}	2.95×10^{-8}
113	M	5.10×10^{-9}	4.10×10^{-8}
126	M	2.92×10^{-8}	2.44×10^{-8}
127	M	1.25×10^{-8}	2.21×10^{-8}
131	M	1.93×10^{-8}	2.97×10^{-8}
136	M	3.06×10^{-8}	3.80×10^{-8}
138	M	2.59×10^{-8}	3.80×10^{-8}
142	M	5.28×10^{-9}	1.38×10^{-8}
157	M	2.98×10^{-8}	3.05×10^{-8}
164	M	5.82×10^{-7}	9.84×10^{-7}
169	M	1.79×10^{-7}	1.22×10^{-7}
170	M	1.91×10^{-9}	2.52×10^{-8}
182	M	1.30×10^{-7}	1.33×10^{-7}
188	M	1.44×10^{-6}	9.51×10^{-7}
222	M	1.48×10^{-8}	1.66×10^{-8}
235	M	2.38×10^{-7}	1.97×10^{-7}
274	M	2.61×10^{-8}	1.97×10^{-8}
276	M	1.94×10^{-6}	1.94×10^{-6}
278	M	1.57×10^{-6}	2.00×10^{-6}
284	M	2.95×10^{-7}	4.26×10^{-7}
285	M	5.08×10^{-7}	9.84×10^{-7}
287	M	1.27×10^{-6}	1.55×10^{-6}
290	M	2.45×10^{-7}	5.57×10^{-7}
293	M	7.70×10^{-8}	2.62×10^{-7}
295	M	1.47×10^{-7}	7.05×10^{-8}
296	M	2.52×10^{-7}	3.61×10^{-7}
300	M	2.11×10^{-7}	1.34×10^{-7}
306	M	1.62×10^{-7}	5.25×10^{-7}
310	M	1.51×10^{-6}	1.51×10^{-6}
319	M	1.79×10^{-7}	1.34×10^{-7}

Table D2. con't.

Relay No.	Flow	Q_S^R(atm. cc/sec.)	$Q_s^{MS} \times \bar{R}$(atm.cc/sec.)
1	S	2.59 x 10-7	3.56 x 10-7
4	S	6.23 x 10-7	6.93 x 10-8
8	S	7.48 x 10-7	1.45 x 10-7
9	S	1.09 x 10-7	5.40 x 10-7
15	S	7.98 x 10-8	3.49 x 10-7
20	S	9.89 x 10-7	1.93 x 10-6
24	S	7.33 x 10-7	2.09 x 10-6
34	S	2.03 x 10-7	2.83 x 10-7
37	S	3.94 x 10-8	5.96 x 10-8
50	S	2.57 x 10-8	9.50 x 10-8
51	S	9.14 x 10-7	1.40 x 10-6
53	S	1.29 x 10-6	1.40 x 10-6
56	S	1.27 x 10-7	8.34 x 10-8
59	S	9.77 x 10-8	1.33 x 10-7
67	S	9.83 x 10-8	1.86 x 10-7
83	S	6.81 x 10-7	8.15 x 10-7
85	S	1.53 x 10-7	2.19 x 10-7
114	S	2.48 x 10-9	1.91 x 10-8
116	S	1.63 x 10-9	2.06 x 10-8
117	S	8.77 x 10-8	1.08 x 10-7
120	S	1.93 x 10-9	4.33 x 10-8
134	S	1.47 x 10-8	4.84 x 10-8
151	S	3.00 x 10-8	8.85 x 10-8
154	S	8.21 x 10-8	9.97 x 10-8
177	S	5.70 x 10-7	3.78 x 10-8
186	S	9.13 x 10-7	6.51 x 10-7
194	S	2.80 x 10-9	7.80 x 10-8
204	S	1.76 x 10-7	1.51 x 10-7
210	S	4.18 x 10-7	8.68 x 10-7
241	S	2.15 x 10-7	3.25 x 10-7
243	S	4.06 x 10-7	5.55 x 10-7
271	S	7.83 x 10-7	4.66 x 10-7
273	S	8.60 x 10-8	9.80 x 10-8
286	S	4.48 x 10-7	1.38 x 10-6
299	S	6.67 x 10-7	1.12 x 10-6
308	S	6.30 x 10-7	1.68 x 10-6
314	S	1.35 x 10-7	4.66 x 10-7
21	P	6.37 x 10-8	4.27 x 10-7
30	P	7.63 x 10-9	7.91 x 10-9
36	P	4.44 x 10-8	2.38 x 10-8
42	P	1.42 x 10-8	2.80 x 10-8
49	P	3.01 x 10-9	8.12 x 10-9
93	P	1.33 x 10-8	6.80 x 10-9
98	P	1.25 x 10-8	1.40 x 10-8
101	P	6.54 x 10-9	3.60 x 10-9
135	P	8.07 x 10-9	7.35 x 10-9
147	P	9.92 x 10-9	7.98 x 10-9
163	P	8.68 x 10-9	1.15 x 10-8
215	P	1.16 x 10-7	1.19 x 10-7

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